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ASD-TDR-62-668

# DEVELOPMENT OF SEALED SILVER OXIDE-ZINC SECONDARY BATTERIES

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Technical Documentary Report No. ASD-TDR-62-668

October 1962

Flight Accessories Laboratory  
Aeronautical Systems Division  
Air Force Systems Command  
Wright-Patterson Air Force Base, Ohio

Project No. 8173, Task No. 817304

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(Prepared under Contract No. AF 33(600)-41600  
by Delco-Remy Division of General Motors Corporation,  
Anderson, Ind.  
Authors: J. J. Lander, J. A. Keralla)

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Aeronautical Systems Division, Dir/Aero-  
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Final report, Oct 62, 142p incl illus,  
tables, 263 refs.

Unclassified Report

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ASD-TDR-62-668

FOREWORD

This report was prepared by Delco-Remy Division of General Motors Corporation, Anderson, Indiana, on Air Force Contract No. AF 33(600)-41600, under Task Nr. 817304 of Project Nr. 8173, "Silver Oxide-Zinc Battery Program". The work was administered under the direction of Flight Accessories Laboratory, Wright Air Development Division;\* Mr. J. E. Cooper was task engineer for the laboratory.

The studies cover the period of 30 June 1960 to 30 June 1962.

The assistance of Dr. T. P. Dirkse, Professor of Chemistry, Calvin College, Grand Rapids, Michigan, as consultant on this project is greatly appreciated.

This is the final report on the contract.

\*Now designated Aeronautical Systems Division.

ABSTRACT

A research and development program has been carried out with the objective of providing an hermetically sealed silver oxide-zinc battery for use in satellite applications.

Part I consisted of a literature review and component research in the following basic problem areas:

- one, silver migration in the cell
- two, battery voltage regulation
- three, zinc particle size and displacement during cycling
- four, gas evolution
- five, terminal sealing

In Part II, sealed cells were designed, constructed, and tested electrically and environmentally. Eighty-nine cells were cycled to failure.

On the basis of cell testing, batteries were designed, constructed and life cycle tested in Part III of the program. Twelve batteries were cycled to failure; one additional battery was tested environmentally.

A final specification for battery construction was prepared and ten batteries were constructed according to this specification for delivery to the Flight Accessories Laboratory.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

## REQUIREMENTS

A major design goal for batteries developed under this program was 5000 continuous cycles at  $27.5 \pm 1.5$  volts while operating in the temperature range  $0^{\circ}$  F. to  $100^{\circ}$  F. in vacuum of  $10^{-9}$  mm Hg and in a zero gravity environment. A cycle is defined as 35 minutes discharge at 20 amperes followed by 85 minutes charge.

It was proposed that a life of 500 cycles be considered as initially acceptable for operation in the temperature range  $32^{\circ}$  F. to  $100^{\circ}$  F. at  $27.5 \pm 1.5$  volts. Vacuum testing at  $10^{-2}$  mm Hg in lieu of  $10^{-9}$  was proposed in view of equipment limitations. Operation in a zero gravity field could not be tested.

It was estimated that an energy-to-weight ratio of about 30 watt-hours per pound might be achieved.

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PART I

LITERATURE SURVEY AND

COMPONENTS RESEARCH

PART I

I. Introduction

The specific application for a battery developed under this contract brings to light two major problems associated with the silver-zinc battery system.

First, the silver-zinc battery is not a good natural secondary battery because the electrode reaction products are soluble in the electrolyte to an extent which results in major separation problems. The zinc discharge product is extremely soluble and does not tend to go back to its original form or position on the electrode during charge, resulting in rapid deterioration of performance.

Second, the space environment necessitates sealing of cells; consequently, because of danger of excessive pressure build up, over charge or over discharge with attendant gassing at the electrodes cannot be allowed unless provision is made for removing the gases as fast as they are formed.

Consideration of the reactions involved and the known behavior of silver oxide-zinc batteries led to the breakdown of the over-all problem into five subproblem areas:

1. The prevention of the silver-ion migration in the cell.
2. The regulation of the battery voltage during discharge to  $\pm 1.5$  volts.
3. The control of zinc particle size and displacement during cycling.
4. Reduction or control of gas evolution.
5. The development of a method of providing a hermetic cell terminal seal.

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Research in each of the problem areas was carried out simultaneously as recorded in subsequent sections of this report.

## II. Literature Survey

A survey of available literature was conducted on the silver oxide-zinc secondary battery system. This survey covers previously reported work in the open scientific literature, patent files and reports of research work done by the United States government organizations or under contract to them.

A listing of all references is given in Appendix I. The number of references that contributed specific information on the problem subjects were relatively few.

## III. Silver Ion Migration

This has long been one of the major causes of cell failure in the silver-zinc secondary battery system. In the course of cycling the  $\text{AgO}$  or  $\text{Ag}_2\text{O}$  dissolves in the  $\text{KOH}$  electrolyte and is transported through the separator system and finally reacts with the negative electrode causing short circuits which result in cell failure.

Various methods have been suggested or developed over the years to control the migration of the soluble silver or of the colloidal silver particles which may be thrown from the positive plate during charge.

The earliest successful method was the use of a regenerated cellulose membrane.

Although membranes of the regenerated cellulose have been successfully used, they have the limitation of acting as a reducing agent toward

the silver oxide plate, thus causing deposition of metallic silver on and within the membrane. This will eventually lead to the deterioration of the membrane and the establishment of electronically conductive paths within the cell and cause cell failure.

A series of three plate cells were set up using one silver positive and two cadmium negatives with multiple layers of separators between plates.

The separator materials tested were:

1. Cellophane, .0015 inch thick
2. Fibrous Sausage Casing, .003 inch thick
3. Clear Sausage Casing, .0015 inch thick
4. Polypor WA, Ion exchange membrane
5. Polypor WA, PVA, Ion exchange membrane
6. Polypor WA, WB, Ion exchange membrane
7. EM 387, Dynel, Nylon non-woven fabric

Each separator combination studied was tested in 5 cell groups in 10%, 25%, 33%, 40% and 45% KOH concentrations. All tests were conducted at room temperature, except for one series which was cycled at 100° F. All cells were given the two-hour cycle schedule of 85 minutes charge and 35 minutes discharge.

The data obtained is shown in Table 1, Appendix I. Results are given in milligrams of silver per square inch of separator material for each layer of separation used in the system.

Silver analysis was conducted on each separator combination at the indicated cycles up to a maximum of 280 cycles.

In the cells using 10% KOH, it was not possible to obtain more than

120 cycles, due to the inability of the plates to accept charge in the 85 minute charge cycle with the resultant loss of capacity during the 35 minute discharge.

Figure 1, Appendix I, shows the results of total silver content of separators after 275 cycles as a function of KOH concentration.

When an inert or ion-exchange type separator is used next to the positive plate, it is observed that the cellulosic separators following contain the least amounts of deposited silver when 40% KOH electrolyte is used.

#### IV. Battery Voltage Regulation and Control of Gas Evolution

In an effort to control battery discharge voltages to  $\pm 1.5$  volts, it is proposed to operate on the monovalent silver oxide level during the charge-discharge sequence and while doing so remain well within the voltage gassing limits so that sealed operation could be safely maintained.

The classic method of sealed cell operation is to absorb the produced gases of  $H_2$  and/or  $O_2$  during charge at the negative and positive electrodes respectively. However, in the silver-zinc system, the silver oxide electrode cannot take up the  $H_2$  at appreciable rates of overcharge and the type of non-porous separators required would prohibit the zinc negative electrode from taking up the  $O_2$  produced at appreciable rates of overcharge.

Figure 2, Appendix I, illustrates a typical voltage charge and discharge curve of a cell under the two-hour cycle program. On charge most of the voltage produced is at the divalent level, while on discharge, a small portion of the voltage produced is at the divalent level. The

voltage areas in which gas is produced is shown on the right hand side of the curves. It may be seen that at the 2.0 volt level on charge gassing commences and should the charge proceed, considerable gas would be produced. On the discharge, gassing commences at the voltage indicated and voltage decay is so rapid that cell reversal is immediate and violent gassing would ensue.

The dotted voltage lines indicated for charge and discharge represent operation on the monovalent silver oxide only. As is indicated these levels are well within the gassing voltages of the system.

In order to change the charge-discharge characteristics of the silver electrode, various metals were alloyed with silver. The most promising of these was palladium.

Figure 3, Appendix I, illustrates the effect of palladium on the silver electrode during charge and discharge. Here the palladium treated electrode shows increased capacity, improved charge acceptance, and improved voltage regulation in comparison with the standard positive electrode. Also the initial experiments with palladium additions show much promise in enabling operation at the monovalent voltage level which would result in much closer voltage control and elimination of oxygen gassing at the silver electrode. However, additional work is necessary before palladium additions can be recommended for battery use.

For the present, the battery operation must be controlled by strict adherence to known voltage gassing points of the untreated silver electrode, and to remain well within these limits during the two-hour cycle.

## V. Zinc Electrode

The problems of the zinc electrode may be resolved into two separate, though inter-related, problems: the control of the position of the zinc within the cell structure and the control of the size of the zinc particles during recycling.

The ability of the zinc reaction product, zincate ion, to produce supersaturated solutions is the cause of one of the major problems in controlling the displacement of the zinc during cycle life. The zincate solution may migrate through the separator system to areas away from the plate. Precipitation may then occur upon aging of the supersaturated solution, causing a deposit of zinc oxide between layers of the separator, within the separator, or in other free areas of the cell pack. Even if precipitation of the zinc compound does not occur, the presence of the supersaturated zincate solution in areas away from the negative plate provides a source of zinc for extraneous plate growth. The presence of the zinc containing ions in the membrane separator promotes the formation of metallic zinc crystals within the separator structure, thus eventually causing a short in the cell.

Various means have been proposed to control the problem. These fall roughly into three classes:

1. The use of membrane structures and binders to contain the zinc compounds around the grid.
2. The use of additives to hasten the precipitation of the supersaturated solutions.
3. The use of mechanical pressure and restriction of the quantity of electrolyte available at the plate.

Experimental three-plate cells were constructed similar to those used for the study of the silver migration with the following separator combinations:

1. 5 layers of .0015 inch cellophane
2. 2 layers of .003 inch fibrous sausage casing
3. 4 layers of Polypor WA
4. 1 layer of Polypor WA, 1 layer cellophane.

Figure 4, Appendix I, shows the numbers of cycles obtained by cells using these separator combinations. It is to be noted that when polyethylene oxide is mixed with the zinc electrode as a binder material, the cycle life is considerably increased as is indicated by the lines over separator combinations 1 and 2.

This binder material was used in the zinc electrode only in conjunction with the separators that showed the most promise during the early testing.

#### VI. Cell Case and Terminal Seal

At the time this work was begun, there was no information regarding pressure conditions which might exist in a sealed cell and, of course, this would depend on the mode of operation. However, a metal-to-plastic seal had to be provided to accommodate the terminal posts in a cell container. The seal was required to be stable in concentrated caustic for a one-year minimum period and resistant to gas leakage over a wide range of temperature change and pressure variations. The terminal seal would have to be compatible with the electrochemical system, of course.

In all, ten combinations of plastic-to-metal seals were tested under a rigorous test of the following type.

A metal pin (brass) was molded into a plastic cup and 30% potassium hydroxide was added to the cup. The cup was then placed in a pressure fixture and tested at 30 psi for four hours to eliminate defective

samples. The cup was then temperature cycled by cooling to  $-30^{\circ}$  F. for 20 hours and heating to  $160^{\circ}$  F. for four hours. It was then automatically pressure cycled 5 minutes at 60 psi, 5 minutes at atmospheric pressure for 24 hours. The whole procedure was repeated to failure of the samples as determined by leakage of the alkali through the metal-to-plastic seal.

The best lot tested consisted of a brass pin coated with Formvar molded in nylon.

Figure 5 shows the experimental cell cover and container design which resulted from the research efforts in obtaining an effective metal terminal-to-plastic seal.

## VII. Conclusions

From the research investigations of the component parts that make up a silver oxide-zinc secondary cell, the following findings and recommendations can be made in order to construct a cell that can meet the proposed specification of 500 cycles:

### 1. Silver Migration in the Cell

The results of this study show that the concentration of KOH electrolyte has a great influence on the solubility of the  $\text{Ag}_2\text{O}$ . The maximum in solubility (and amount of silver in the separator system) was found to be in the region of 30% KOH. Electrolyte concentration in the region of 40 to 45% caused a considerable decrease in the amount of silver present in separator layers.

It has been found that the use of an inert separator against

the positive plate, followed by three layers of fibrous casing material, effectively prevents silver migration from causing cell failure until well over the proposed cycle life (500) is achieved.

While this particular separator combination has been found to give the most promising results, additional research investigations must be made of new membrane materials that may ultimately result in fewer and thinner layers to give the same protection presently obtained and thus enable the battery to give a higher energy-to-weight ratio.

## 2. Negative Electrode Study

Investigation of the effect of cycling on the zinc electrode has been studied in terms of current density and depth of discharge and certain additives embodied in the negative active material. It is concluded that current density has a large effect on the growth of particle size.

The growth of dendritic zinc and extraneous sponge zinc which will result in shorts between plates may be controlled to a great extent by proper design of the cell, which determines current density, and the choice of separator material.

The effects of binder material in the negative material increases the cycle life, but further work is necessary in order to maintain capacities and voltages, which may decrease when binder materials are used.

## 3. The Reduction or Control of Gas Formation

It was determined that both the positive and negative plates are capable of reacting with the gas which is produced at the plate

of opposite polarity during overcharge. The reactions are relatively slow, especially for the positive plate-hydrogen reaction.

The effect of the presence of separators, excess electrolyte, and various concentrations of electrolyte have not been investigated.

Additional work with palladium as an additive to the positive plate must be accomplished before definite recommendations as to its permanent effect on voltage throughout the life of the plate can be assured.

Procedure of the cell testing program will be governed by operation between upper and lower voltages of charge and discharge to eliminate or minimize attendant gassing.

It was decided not to attempt to operate on the monovalent level of silver oxidation, because the energy yields would be too low, and it will be seen in Parts II and III that the upper voltage on charge was established by minimum gassing rates consistent with full recharge of cells and batteries.

#### 4. Case and Terminal Seal

A plastic-to-metal seal has been developed that will withstand a 0 to 60 psi pressure cycle and  $-30^{\circ}$  F. to  $160^{\circ}$  F. temperature cycle for long periods of time without electrolyte leakage. This is a nylon injection molded sample with a metal insert which is coated with Formvar prior to molding.

PART II

TESTING OF SEALED SILVER OXIDE -

ZINC SECONDARY CELLS

## PART II

### ADMINISTRATIVE DATA

#### Purpose of Tests:

The purpose of the tests was to develop in compliance with contract No. AF 33(600)-41600, Item II, a sealed silver oxide-zinc secondary cell capable of delivering at least 5000 two-hour cycles within a temperature range of 0° F. to 100° F. This cell shall be capable of enduring environmental conditions of vibration, acceleration, shock as prescribed by Mil-E-5272C, and withstand a pressure approaching  $10^{-3}$  mm Hg in a zero gravity environment. The final design of the cell shall be consistent with minimum weight and volume for a prototype battery operating in a voltage range of  $27 \pm 1.5$  volts.

Note: A cycle is defined as a 35 minute discharge at 20 amperes and an 85 minute recharge. Failure is determined by any cell unable to deliver 1.30 volts at the end of the 35 minute discharge.

It was originally proposed (DRD-102) that a minimum of 500 two-hour cycles in the temperature range of 32° F. to 100° F., while operating in the voltage range of  $27.5 \begin{smallmatrix} + 5 \\ - 1.5 \end{smallmatrix}$  volts be considered in a first attempt at meeting the desired goal.

Under the environmental requirements the zero gravity was accepted but cannot be tested, and a vacuum approaching  $10^{-2}$  mm Hg be used, because this can be accomplished with existing test chambers. This procedure has been followed to date.

Manufacturer: Delco-Remy Division of General Motors Corporation

Manufacturer's Type or Model No: 25 a.h. silver oxide-zinc secondary cell

Drawing Specification or Exhibit: X-44888

Quantity of Items Tested: 89 sealed cells

Security Classification of Items: Unclassified

Date Test Completed: October 1961

Tests Conducted By: Delco-Remy Division of General Motors Corporation

FACTUAL DATA

Description of Test Apparatus:

Throughout this cell testing program, the following equipment was used as pictured in Figure 6 and 7, Appendix II.

1. Constant potential charger type TRM 40-120 manufactured by the NJE Corporation (Fig. 5).
2. Battery cycle timer manufactured by Delco-Remy Division of General Motors Corporation (Fig. 6).
3. 24 point recording voltmeter
4. Two 0-3 volt Weston 901 D.C. voltmeters
5. Two 0-500 ampere Weston 901 D.C. ammeters with appropriate 50 mv shunts.

All of these instruments were new from the manufacturer and calibrated just prior to the start of this program. All cycles were run automatically.

Test Procedure:

Contract No. AF 33(600)-41600, Item II, of the work statement calls for design fabrication and testing both electrically and environmentally of sealed silver oxide-zinc secondary cells. The requirements are stated under Purpose of Tests.

The basic variables considered necessary for study during the cell-development program were:

1. Separators
2. % depth of discharge
3. Current density
4. Cell sealing
5. Environment

In general, an attempt was made to develop a sealed cell to deliver the highest watt-hour per pound utilization for a minimum 500 cycles through the best combination of these variables.

Of the 89 cells discussed in this report, the first three were constructed prior to the start of this test program and were of a nominal 48 a.h. capacity. They were discharged in series, as a battery, at 20 amperes through a constant resistance load and recharged at a constant potential to 1.97 volts per cell. These cells were tested early in an effort to determine the possibility of reaching 500 cycles under this program.

Nine cells were of a nominal 18 a.h. capacity representing a 29% depth of discharge. Nine cells were of a nominal 13 a.h. capacity representing a 40% depth of discharge. The bulk of the remainder of the cells were of a nominal 25 a.h. capacity, discharged at 9 amperes through a constant resistance load and recharged at constant potential to 1.97 volts per cell.

An attempt was made to cycle some cells at 0° F. under varying depths of discharge. Early cycles (5 to 10) showed that at 0° F. the internal resistance of the cells was so high that full recharge in a time of 85 minutes was being rejected by the cells, and cell reversals

were encountered during discharge. Subsequently, the minimum temperature was raised to 30°F. for the remainder of the life cycle test.

The first sixty-five cells were made with lucite jars equipped with pressure gauges, while awaiting molded nylon jars and covers with the metal terminal-to-plastic seal. Some cells in the lucite jars ruptured due to bad jar seals. This rupturing was not due to excessive gas pressure build-up but to expansion of separator membranes.

The eighty-nine cells tested may be divided into five major groups. Group 1 consisted of thirty cells employing various separator combinations and certain methods of negative plate processing.

Group 2 consisted of twenty-seven cells to determine cycle life at varying depths of discharge at three different temperatures. The current density varied as the depth of discharge.

Group 3 consisted of eight cells employing new separators recently available and some repetition of cells in Group 1 that failed due to cell container breakage.

Group 4 consisted of sixteen cells constructed in molded nylon containers and covers with the metal terminal-to-plastic seal. Eight of these cells incorporated the best features resulting from testing the cells in Groups 1, 2 and 3. These features are:

1. Separation: 1 layer Dynel, 4 layers fibrous sausage casing
2. Electrolyte: 40% KOH - saturated ZnO
3. Negative Plate: Polyvinyl alcohol added to the ZnO-HgO mix
4. Current density: .070 amps/in<sup>2</sup>; this entails 21% depth of discharge.

Three of the first eight cells in this group were used in the environmental tests.

The other eight cells of Group 4 contained the above features except that no polyvinyl alcohol was added to the negative plate mix, but an excess of ZnO was used. These cells were designed primarily to prove out manufacturing techniques in making sealed 25 a.h. rated cells and to test the seal features.

Group 5 consisted of eight cells employing the best features of all the previous cells and represents the initial cell design developed in this program to meet the cell requirements stated in the Purpose. These features for four cells are:

1. Separation: 1 layer Dynel, 3 layers fibrous sausage casing
2. Electrolyte: 40% KOH - saturated ZnO
3. Current Density: .052 amps/in<sup>2</sup>
4. Negative Plate Process: Polyvinyl alcohol added to ZnO-HgO mix.

The features of the remaining four cells are the same except that the use of a polyethylene base ion exchange membrane in place of Dynel and excess ZnO in place of polyvinyl alcohol.

All cells in the program were given a capacity discharge on the first cycle and then placed on automatic life cycle test. The end of life was determined when any cell failed to deliver 1.30 volts at the end of the 35 minute discharge.

The construction features of these cells are described in Appendix II, Test Summary Sheets 1, 2 and 3.

The electrolyte used throughout the test was 40% KOH-zinc saturated. This concentration was chosen because the silver migration is apparently less in 40% KOH than at lower concentrations, and 40% KOH is more suitable for a wider range of temperature operation than higher concentrations.

A constant potential charge was used to insure 98 to 100% charge returned to the cells. This resulted in consistent end-of-charge voltages.

Figure 8 shows typical current-time curves for charge and discharge of cells in this program.

Results of Tests:

Group 1, Cells A, B and C:

These cells failed at 1760 cycles. Figure 9 shows end of charge and discharge voltages and pressures for 1760 cycles. The cause of failure was due to corrosion of the positive plate lugs but the positive plates were in excellent condition. The separators were in excellent condition. They maintained the same pliant strength as is usually evident in cells after 10 to 20 cycles under other cycle conditions. Figure 10 shows silver content analysis in the separators of the three cells.

The negative plate material did not grow in any direction and remained encapsulated in one wrapping of separator material. There was no evidence of washing of negative material from the grid. The material itself appeared coarse and gritty to the touch, but it is estimated that if the positive lugs had not corroded, this battery would have continued cycling well over 2000 cycles. Figure 11 shows typical charge and discharge current-time curves over 1760 cycles.

The remaining 27 cells in this group were constructed to test minimum design parameters that would permit at least 500 cycles.

Cycle life obtained by these cells is shown in Appendix II, Figure 12. Cause of failure is described in Appendix II, Test Summary Sheet 1.

Group 2, Cells 28 through 54:

These cells were cycled at 30° F., 80° F., 100° F. at depths of discharge of 21%, 30% and 40%. Figure 13, Appendix II, shows end-of-discharge voltages for these cells throughout cycle life. Cause of failure at low temperatures was the inability of the cells to accept sufficient recharge within the 85 minute charge period. Cells failing at 30° F. were subsequently recharged and cycled at room temperature and gave 400 to 600 cycles.

At room temperature and 100° F., a main cause of failure was washing or shedding of the negative active material. Cause of failure of cells in this group are described in Appendix II, Test Summary Sheets 1 and 2.

Group 3, Cells 55 through 62:

These cells were constructed with new separator material recently available and some repetition of cells in Group 1 that contained negative plate binders that failed due to container breakage.

Figure 14, Appendix II, shows the number of cycles obtained by these cells. Test Summary Sheet 2, Appendix II, describes the cause of failure of these cells.

Group 4, Cells 63 through 78

Figure 15, Appendix II, shows the number of cycles obtained by these cells. Three of these cells (#68, 69 and 70) were made up in a battery that underwent environmental testing.

Since a complete description of these environmental tests are included in Part III of this report, the test descriptions will not be repeated here. Figures 16, 17, and 18, Appendix II,

show the battery charge and discharge curves under vibration, shock, acceleration and vacuum conditions.

Test Summary Sheets 2 and 3 describe the cause of failure of cells in this group. It is to be noted that in all 16 cells in this group, the major cause of cell failure is a crack along the bottom edge of the container. This occurred because the inside radius of the corners of the container was too sharp, and strains were incurred due to internal pressures of swelling membranes and probably some gas pressure.

This radius was subsequently increased and was taken in account when the molds were made for the containers used in the battery program described in Part III of this report.

#### Group 5, Cells 79 through 86

Figure 19, Appendix II, shows the number of cycles obtained by these cells. Test Summary Sheet 3, Appendix II, describes the conditions of failure of these cells.

Figure 20 and 21 illustrate the condition of cell #85 after 837 cycles and illustrate the type of short circuit resulting from dendritic zinc growth.

## DISCUSSION

### Test Cell Design:

Cells tested in Groups 1, 2, 3 and 4 were designed to check out the variables listed in the Test Procedure with a more-or-less arbitrarily selected nominal capacity (25 ampere-hours), plate number (13), plate thickness (0.020" positives and 0.040" negatives) and area (10 sq. in.).

Twenty-five ampere hours is sufficient capacity for problems of scale-up in size to be felt so a good approximation of the final cell design to meet the ampere hour requirement (20 amperes for 35 minutes with an 85 minute recharge) could be made.

It was desirable to keep the number of plates to a practical minimum to reduce the total weight and thickness of separation necessary. It is known that the watt hour per unit weight and volume yield of secondary batteries will increase as number of plates per cell is reduced because the separator thickness term is a not-inconsequential contribution to cell weight and volume where cycling life is desired. (Interim Report No. 1, Delco-Remy Project No. 4260-K, "The Effects of Plate Thickness and Electrolyte Concentration on Energy Yield of Secondary Silver Oxide-Zinc Cells at Various Discharge Rates," July 5, 1961). The major reason for use of multiple layers of separation is silver deposition in the separator material; where failure is limited by this factor, cycle life is strictly a matter of separator thickness.

On the other hand, high-rate performance is generally improved by designing for more and thinner plates, and the two-hour cycle time involved in this proposal may be considered to be a high rate situation. The terminology "high rate performance" includes rechargeability of the

cell also. It is also possible, as will be discussed, that thinner plates lead to longer cycle life.

Substantially then, the design tested represents an attempt at compromising the known design factors to obtain higher energy per unit weight and volume yields, in the absence of any detailed knowledge as to how the design parameters would affect life, except for the accumulated knowledge about silver penetration of separators.

#### Minimum Separation:

From testing during Part I, it was found that one layer of the best available material, i.e., strengthened regenerated cellulose, would allow less than 100 cycles. From the results of testing of Group 1 cells, #1 through #12 where various numbers of layers of FSC and cellophane were used, life is increased to 300 - 900 cycles by adding additional layers of separation.

#### Use of Dynel Next to Positive Plate:

The results of testing for silver migration in Part I showed that the use of thin, inert, but porous layer, such as Dynel, next to the positive plate reduced silver penetration. It is evident from testing of cells #22 through #27 that the use of Dynel does extend cycling life, although the results do not allow a quantitative measure of additional life due to this cause because the nature of failure changed. A polyethylene base type of ion-exchange membrane has a similar effect (cells #59 through #62).

#### Use of Polypor:

Polypor, from Phase I testing and additional work in these tests, is no more effective in stopping silver penetration than an equivalent thickness

of cellophane or FSC and consequently is regarded as having no additional beneficial properties.

Negative Plate Additives:

Solka Floc, a fine fibrous inert material, was added to the negative mix in an effort to reduce negative plate washing (cells #16, 17 and 18). While these cells failed due to shorting, there was no evidence that Solka Floc was effective in retaining zinc.

Polyethylene oxide showed capability of retaining zinc as did the use of polyvinyl alcohol. Both these addition agents also seemed to increase time to shorting failure, probably because they help keep the zinc in place.

Negative Plate Washing:

With increase in separator thickness, negative plate washing became the chief cause of failure where additives to negative material were not used or were ineffective. The use of PVA has resulted in reducing negative plate washing and cycle life for this design has achieved 600 cycles consistently (cells #63 through #70).

Temperature:

Cells will not cycle at 0° F. at discharge depths as low as 21% due to lack of rechargeability. Some life is obtained at 30° F. at 21% depth of discharge, but early failure occurs because of lack of rechargeability. At room temperature and 100° F., cells accept charge and failure is due to other causes.

Depth of Discharge:

It is evident that increasing the depth of discharge decreases the

cycle life where negative plate washing is the cause of failure. Other types of batteries, i.e., lead-acid and nickel-cadmium, also exhibit shortened life due to increased depth of discharge.

Current Density:

There is some evidence that distributing current over a larger number of plates per cell will be effective in increasing life. Cells A, B and C, although of a different ampere-hour capacity (48), yielded 1760 cycles at 21% depth of discharge with very little evidence of negative plate deterioration. The obvious cause is reduction of current density per plate, although other contributing causes may be present.

While cycle life may be improved by going to thinner plates on the basis of present knowledge, it seems that this is likely to be at the expense of reduced performance on a weight and volume basis. Other benefits are expected to accrue, however, from reduction in plate thickness, specifically better rechargeability and increased cold performance.

When separation and negative plate additives are checked out, the question of optimum design for best cycle life and energy performance needs evaluation.

PART III

TESTING OF SEALED SILVER OXIDE-ZINC

SECONDARY BATTERIES

ADMINISTRATIVE DATA

Purpose of Tests:

The purpose of the tests was to develop in compliance with contract No. AF 33(600)-41600, Part III, a sealed silver oxide-zinc secondary battery capable of meeting the requirements previously outlined in Part I and Part II of this report.

Manufacturer: Delco-Remy Division of General Motors Corporation

Manufacturer's Type or Model No.: 37 a.h. silver oxide-zinc secondary battery

Drawing Specification or Exhibit: X-44926

Quantity of Items Tested: 13 sealed batteries

Security Classification of Items: Unclassified

Date Test Completed: June 1962

Tests Conducted By:

Electrical Tests: Delco-Remy Division of General Motors Corp.

Environmental Tests: Cook Testing Laboratories

ELECTRICAL TESTS

COOK TESTING LABORATORIES

Environmental Tests

Disposition of Specimens: 12 batteries inspected and scrapped. One battery undergoing cycle life tests at room temperature following completion of environmental tests.

## FACTUAL DATA

### Description of Test Apparatus:

Throughout the battery testing program the following equipment was used:

1. Constant potential charger type TRM 40-120 manufactured by the NJE Corporation
2. Battery cycle timer manufactured by Delco-Remy Division of General Motors Corporation
3. 24 point recording voltmeter
4. Three 0-150 volt Weston 901 D.C. Voltmeters
5. Six 0-500 ampere Weston 901 D.C. Ammeters with appropriate 50 mv shunts

All of these instruments were new from the manufacturer, and although used in the cell testing program, were recalibrated prior to the start of the battery testing program.

All cells were run automatically. Figure 22, Appendix III, shows the batteries in cycle operation with individual resistors for discharge.

### Test Procedure:

Contract No. AF 33(600)-41600, Item III, of the work statement calls for design, fabrication and testing both electrically and environmentally of sealed silver oxide-zinc secondary batteries under a two-hour cycle regimen with a design goal of at least 5000 such cycles throughout a temperature range of 0°F through 100°F, maintaining a seal sufficient to withstand pressure of at least  $10^{-2}$  mm Hg.

The batteries were cycled electrically and environmentally tested under the reduced requirements previously stated in Part I and Part II of this report.

Twelve batteries were electrically tested over the six month period. These batteries were used to test out various separator systems, and negative binder materials that showed merit in the cell testing program. Cycling in the temperature ranges of 50°F., 80°F (R.T.), 100°F. was also accomplished.

Aside from the separator combinations utilized, the general construction features of these batteries consisted of 18 cells of 39 plates each. The batteries are rated at 37 a.h. at the one-hour rate. All initial and subsequent discharges were run at 20 amperes. The batteries weighed 40 to 42 pounds complete, realizing an energy-to-weight ratio of  $7\frac{1}{2}$  watt hrs/lb.

Tables 2 and 3, Appendix III, describe in detail the construction features of these batteries.

#### Results:

Note: Throughout this program a battery was called a failure when a loss of three cells occurred. Cycling was continued until a total of 9 cells failed, on the last six batteries only, where upon the battery was removed from the cycle panel and torn down for inspection.

Battery #1, cycling at room temperature, failed at 160 cycles. The cause of failure is attributed to dry cells caused by the apparent inability of the two layers of polyethylene base separation to wet properly. The activation or initial filling of this battery was extremely difficult, as only small portions of electrolyte could be added to the cells at a time. In general, cells showed a gradual loss in capacity resulting in reversals during discharge.

At the start of cycle life some cells exhibited high end of charge voltage, leaks developed around the cover-to-container seal junction, and some electrolyte loss occurred. The negative plates showed some treeing and considerable creepage over the tops of the separators.

The high charge voltages are attributed to lack of electrolyte near the positive plate which caused a high resistance. Table 4 describes the battery tear-down data of component cells.

Figure 23, Appendix III, shows the initial charge and discharge curves of the battery.

Figure 24, Appendix III, shows the end of discharge voltages, and cell failures during cycle life.

Figure 25, Appendix III, shows this battery at the end of cycle life.

Battery #2, control battery cycling at room temperature, failed at 538 cycles. The cause of failure was heavy shedding of negative active material, zinc treeing across the tops of separators, and shorting against the positive lug. Only one cell-cover-to-container remained sealed throughout cycle life.

Table 5, Appendix III, describes the battery tear-down data of component cells.

Figure 26, Appendix III, shows the treeing of zinc on the top of the negative plate that occurred throughout many cells in these 12 batteries. This treeing would creep over to the positive lugs to cause shorts. Figure 27, Appendix III, shows the initial charge and discharge curves of this battery. Figure 28, Appendix III, shows the end of discharge voltages and cell failures during cycle life of the battery.

Battery #3, cycling at room temperature, failed at 416 cycles. The cause of failure was zinc material shorting across the tops of the separators to the positive lug, and in some cells silver penetration through all layers of separation to the negative plate, causing areas of shorts. Only four cells remained sealed during cycle life. Leaks occurred in other cells at the cover-to-container seal junction.

Table 6, Appendix III, describes the battery tear-down data of the

component cells. Figure 29, Appendix III, shows initial charge and discharge curves for this battery. Figure 30, Appendix III, shows end of discharge voltages and cell failures during cycle life of the battery.

Battery #4, cycling at room temperature, failed at 379 cycles. The cause of failure appeared due to zinc treeing or creeping around the sides or folds of the separators, thus losing contact with the zinc plate. The appearance of the negative plates was very good. There seemed to be adequate zinc material available for considerable more cycles than was obtained. However, these plates were manufactured with 20% polyethylene oxide which was retained in the plates throughout battery life. Only four cells remained sealed throughout cycle life. The remaining cells developed leaks at the cover-to-container seal junction. Table 7, Appendix III, describes the battery tear-down data of the component cells. Figure 31, Appendix III, shows the initial charge and discharge curves of the battery. Figure 32, Appendix III, shows the end of discharge voltages throughout the cycle life of the battery.

Battery #5, cycling at room temperature, failed at 465 cycles. The cause of failure was treeing of negative active material across the tops of the separators causing direct shorts in the case of several cells as indicated by the zero volts open circuit reading.

There was also washing of negative active material in other cells and some cells were developing slow shorts through separators due to holes present. Three cells remained sealed throughout the battery cycle life. The remaining cells developed leaks at the cover-to-container junction.

Table 8, Appendix III, describes the tear-down data of the component cells. Figure 33, Appendix III, shows the initial charge and discharge curves of the battery. Figure 34, Appendix III, shows the end of discharge voltages and failing cells throughout the cycle life of the battery.

Battery #6, cycling at room temperature, failed at 318 cycles.

The cause of failure is the same as for battery #1. While this battery had only one layer of a polyethylene base separator, the initial activation process was very tedious, and again, this is attributed to the inability of the polyethylene base separator to properly wet.

The negative plates showed extensive washing and treeing. Indeed, there appeared to be an extravagant amount of washing for only 318 cycles. This was attributed to high current densities centered unevenly about the negative plate. In general, the appearance of the positive and negative plates showed results of an uneven charge apparently due to poor wetting characteristics of the polyethylene base separator. Again, as in the case of battery #1, cells lost capacity and resulted in some reversals during discharge. Nine cells remained sealed during cycle life; the remaining cells developed leaks at the cover-to-container seal junction.

Table 9, Appendix III, describes the tear-down data of the component cells. Figure 35, Appendix III, shows the initial charge and discharge curves of the battery. Figure 36, Appendix III, shows the end of discharge voltages and failing cells during cycle life of the battery.

Battery #7, cycling at room temperature, failed at 244 cycles. The cause of failure was direct shorts by zinc treeing across the tops of the separators to the positive terminal in the case of six cells. All cells developed leaks in the cover-to-container seal junction.

Table 10, Appendix III, shows the tear-down data for the component cells. Figure 37, Appendix III, shows the initial charge and discharge curves for the battery. Figure 38, Appendix III, shows the end of discharge voltages and cell failures during cycle life of the battery.

Battery #8, cycling at 100°F., failed at 364 cycles. There is no definite cause of failure other than all cells developed leaks at the cover-to-container seal junction, which in itself is not a cause of capacity failure. The open circuit voltages of the cells indicate insufficient charge, or the slow development of short circuits within the

elements. However, the negative plates did not show any creeping of material and hardly any treeing. There was relatively little shedding, but this is to be expected at the low cycles attained. There was considerable silver penetration through six layers of separation material, and it is possible that some silver had deposited on certain areas of the negative active material. This is very difficult to observe in many cases of cell inspection, but a comparison of battery #11, which was also cycled at 100° F, shows silver penetration through only three layers of Dynel and FSC separation. In general, it may be considered that operation at 100° F tended to break down the cellophane separation, which in turn, led to the start of slow short circuits. Again, it must be stated that only the open circuit voltages show the possibility of shorts occurring.

A look at some end of charge cell voltages and following end of discharge voltages will indicate that this battery was receiving a sufficient charge to maintain constant discharge capacities. Table 11, Appendix III, shows the charge-discharge voltages of the cells of this battery at 300 cycles. A comparison of the charge and discharge voltages of battery #11, Table 12, Appendix III, at the same number of cycles show that battery #11 is reading slightly higher cell charge voltages, but the end of discharge voltages are approximately the same as battery #8. An increase of the battery charge voltage was made; no higher end of discharge voltages were attained, and no stoppage in decrease of capacity was noted in subsequent cycles.

Table 13, Appendix III, describes the tear-down data for the component cells. Figure 39, Appendix III, shows the initial charge and discharge curves of the battery. Figure 40, Appendix III, shows the end of discharge voltages and cell failures throughout the cycle life of the battery.

Battery #9, cycled at 50° F., failed at 421 cycles. The cause of failure was loss of capacity due to washing of negative active material.

All the cells appeared to be securely sealed at the cover-to-container seal junction. There were no other apparent leaks.

Table 14, Appendix III, describes the tear-down data for the component cells of the battery. Figure 41, Appendix III, shows the initial charge and discharge curves of the battery. Figure 42, Appendix III, shows the end-of-discharge voltages and failing cells throughout the cycle life of the battery.

Battery #10, cycled at 50° F., failed at 500 cycles. The cause of failure was washing and treeing of the negative active material causing a gradual loss of capacity in the failing cells. Only two cells had developed leaks in the cover-to-container seal junction; the remaining cells in the battery were sealed throughout cycle life.

Table 15, Appendix III, describes the tear-down data for the component cells of the battery. Figure 43, Appendix III, shows the initial charge and discharge curves for the battery. Figure 44, Appendix III, shows the end-of-discharge voltages and cell failures throughout the cycle life of the battery.

Battery #11, cycled at 100° F., failed at 420 cycles. The cause of failure was excessive washing and treeing of negative active material, causing loss of cell capacities.

All cells developed leaks in the cover-to-container seal junction.

Table 16, Appendix III, describes the tear-down data for the component cells of the battery. Figure 45, Appendix III, shows the initial charge and discharge curves of this battery. Figure 46, Appendix III, shows the end-of-discharge voltages and failing cells throughout cycle life of the battery.

Battery #12, cycling at room temperature, failed at 420 cycles. The cause of failure was washing and treeing of negative active material, causing numerous short circuits. One cell remained sealed during cycle life. The remaining cells leaked at the cover-to-container seal junction.

Table 17, Appendix III, describes the tear-down data for the component cells of this battery. Figure 47, Appendix III, shows the initial charge and discharge curves of this battery. Figure 48, Appendix III, shows the end-of-discharge voltages and failing cells throughout cycle life of the battery.

Figure 49, Appendix III, shows the number of cycles each battery attained before one cell failure.

Figure 50, Appendix III, shows the number of cycles each battery attained before three cells failed. This is considered a battery failure.

Figure 51, Appendix III, shows the number of cycles the last six batteries attained before nine cells failed.

Figure 52, Appendix III, shows the typical charge and discharge current applied to the batteries.

#### Environmental Tests

Battery #13 underwent the following environmental tests. Figure 53, Appendix III, shows the initial charge and discharge curves of the battery.

##### Vibration

##### Requirements:

The sealed silver-zinc battery shall be subjected to a vibration test in accordance with Specification MIL-E-5272C paragraph 4.7.14 procedure XIV. The results of this test shall be recorded and compared with the specified requirements.

##### Test Apparatus:

Vibration Machine, MB Manufacturing Co., M/N C-10

Vibration Meter, MB Manufacturing Co., M/N M-3  
Vibration Pick-up, MB Manufacturing Co., Type 125  
Voltage Recorder, Esterline-Angus, M/N AW  
Ammeter, Weston, M/N 931  
Voltmeter, Sensitive Research, Model University  
DC Supply, Harrison Laboratories, Inc., M/N 814A

Test Procedure:

The sealed silver-zinc battery was mounted in a rigid aluminum fixture which secured the battery along each of the three (3) mutually perpendicular axes. The battery was subjected to a variable frequency vibration scan for resonance from 5 to 20 cps at an amplitude of  $\pm 1$  G or 0.20 inches double amplitude, whichever was the lower value. When resonance occurred the battery was vibrated at resonance for a period of one (1) minute.

The battery was then subjected to a cycling vibration. One cycle consisted of a logarithmic variation of frequency from 20 to 2000 cps and back to 20 cps over a period of one (1) hour. The amplitude of vibration was maintained at  $\pm 10$  G or 0.036 inches double amplitude, whichever was the lower value. The battery was subjected to two (2) cycles along each of the three (3) mutually perpendicular axes. The total cycling vibration time was six (6) hours.

Throughout the cycling vibration the battery was operated as follows:

The battery was discharged at a rate of 20 amps. for a period of 35 minutes.

The battery was then charged at a rate of 9 amps. for a period of 85 minutes.

Figure 54, Appendix III, shows the charge and discharge curves during vibration. Figure 55, Appendix III, shows the battery in one plane during vibration.

Test Results:

A visual examination of the battery following the vibration test, revealed no apparent physical damage. No resonances were encountered during the scan for resonance in any axis.

## Shock

### Requirements:

The sealed silver-zinc battery shall be subjected to a shock test in accordance with Specification MIL-E-5272C, paragraph 4.15.5.1, procedure V.

The test results shall be recorded and compared with the specified requirements.

### Test Apparatus:

Shock Machine, Manufactured per MIL-S-4456

Voltage Recorder, Esterline-Angus, M/N AW

Ammeter, Weston, M/N 931

Voltmeter, Sensitive Research, Model University

DC Supply, Harrison Laboratories, Inc., M/N 814A

### Test Procedure:

The battery was securely mounted to the shock machine and subjected to three (3) impact shocks along each direction of three (3) mutually perpendicular axes. Each impact shock had a time duration of  $11 \pm 1$  milliseconds and an intensity of 40 G's. The battery was subjected to a total of 18 impact shocks.

During the impact shocks, the battery was discharged at a rate of 20 amperes. Figure 56, Appendix III, shows the resultant discharge curve. Figure 57, Appendix III, shows the battery in one axis during shock.

### Test Results:

A visual examination of the battery, following the shock test, revealed no evidence of physical damage.

## Acceleration

### Requirements:

The battery shall be subjected to acceleration testing in accordance with Military Specification MIL-E-5272C, Procedure III, paragraph

4.16.3, except that the applied acceleration shall be 18 G's in each direction along each of the unit's three orthogonal axes. The acceleration shall be applied for three (3) minutes, in each direction, while the battery is discharged at a constant current of 20 amperes and the output voltage is continuously monitored. There shall be no mechanical failures or malfunctions due to the applied acceleration.

Test Procedure:

One (1) silver zinc battery was submitted by Delco-Remy for an acceleration test, conducted in accordance with Military Specification MIL-E-5272C, Procedure III, paragraph 4.16.3, with amendments as described above.

The battery was mounted in a rigid aluminum test fixture and the battery and fixture assembly were then secured to the arm of a centrifuge. A photograph, included in this report, illustrates the mounting means.

Next, electrical leads were connected to the battery and these leads were, in turn, connected through slip rings, to suitable resistive loads and electrical monitoring apparatus.

The battery was then subjected to a steady acceleration of 18 G's for a period of three (3) minutes, in each direction along each of the unit's three (3) orthogonal axes. While acceleration was applied, the battery was discharged at a constant current of 20 amperes and the output voltage was continuously monitored by means of a Brush Oscillograph.

At the completion of each acceleration run, the battery was visually examined for evidence of structural damage.

Description of Test Apparatus:

Centrifuge, Genisco, Model E-185, S/N 6

Oscillographic Recorder, Brush, Model BL-202, S/N 202-56-6289

Shunt, 50 Amp., Weston, S/N 3

Millivoltmeter, Weston, Model 622, S/N 19572

### Test Results:

The battery delivered 20 amperes of current during application of acceleration in each direction along each axis. There were no sudden or erratic voltage changes observed on the oscillographic recorder. A visual examination of the battery during and at the completion of the acceleration test revealed no evidence of physical damage.

Figure 56, Appendix III, shows the resultant discharge curve. Figure 58, Appendix III, shows the battery in one axis during acceleration.

### Vacuum

#### Requirements:

The sealed silver-zinc battery shall be subjected to an absolute pressure of  $10^{-2}$  mm of mercury for a period of six (6) hours. The results shall be recorded.

#### Test Apparatus:

Leak Detector, Consolidated Electrodynamic Corp., M/N 24-101A

Vacuum Pump, Cenco-Hypervac, M/N 93006

Thermocouple Vacuum Gauge, Vacuum Tube Products, Type 6343

Vacuum Gauge Meter, Arthur F. Smith Co., M/N 1010

Bell Jar, Central Scientific Co., 18 inches diameter

Bell Jar Base, Inland Testing Laboratories

Voltage Recorder, Esterline-Angus, M/N AW

Ammeter, Weston, M/N 931

Voltmeter, Sensitive Research, Model University

DC Supply, Harrison Laboratories, Inc., M/N 814A

#### Test Procedure:

The battery was placed on the bell jar base and the battery terminals were connected to the base feed-through terminals. The bell jar was placed over the battery and the atmosphere surrounding the battery was reduced to an absolute pressure of  $10^{-2}$  mm of mercury. The system

was maintained at  $10^{-2}$  mm of mercury for a period of four (4) hours prior to testing.

The battery was subjected to three (3) cycles of discharge and charge. One cycle consisted of discharging the battery at a rate of 20 amperes for a period of 35 minutes and charging the battery at a rate of 9 amperes for a period of 85 minutes.

Figure 59, Appendix III, shows the charge and discharge curves during the vacuum test. Figure 60, Appendix III, shows the battery during the vacuum test.

#### Test Results:

During the time when the pressure was being reduced to  $10^{-2}$  mm of mercury, a small amount of tan sponge-like material emerged from one of the bottom corners of the battery.

During the six (6) hours of discharge and charge the pressure surrounding the battery fluctuated and at one time the pressure reached  $2.5 \times 10^{-2}$  mm of mercury.

A visual examination of the battery, following the vacuum test, revealed no evidence of physical damage.

Figure 61, Appendix III, shows the battery after completion of all tests.

#### Discussion

The first twelve batteries constructed and tested during Part III were designed during the latter part of the cell testing program. Certain design features which proved detrimental to the life of these batteries were disclosed by the tests. These were: insufficient separator height over the tops of the plates, inadequate sealing area around the cover-to-container seal junction, and too much free electrolyte remaining in cells after sealing.

A new container and cover mold was designed which produced a cell

cover and container as pictured in Figure 62, Appendix III. The new case has more seal area, a mechanical lock fit to the cover, and a tongue-in-groove fit to the cover. The cover is snapped on the case after the sealing compound is applied to both mating surfaces of the container and cover.

The entire container is approximately  $3/4$  inches higher than the original design, allowing for an increased height in the separators over the plate tops.

The matter of excess electrolyte that is allowed to remain in the cells has long been a problem in both the cell and battery program. Some cell failures have been attributed to dry conditions, while many cells have failed due to excess electrolyte aiding in the washing of negative active material.

A close review of all cell failures in the overall program that have been attributed to lack of electrolyte has brought to light the fact that in all cases these cells had developed imperceptible leaks sometime prior to failure. It is quite possible that considerable evaporation of water had taken place, and this without the tell-tale marks of carbonation in many cases. Of course, many cells failed that had definite leaks in the cell cover-to-container seal junction, permitting loss of electrolyte in those areas and resulting in so-called dry cells. However, there are a few cases, particularly in cells A, B and C of Part II, which attained 1760 cycles in the absence of any free electrolyte. These cells did not leak.

In the construction of the prototype batteries for shipment and battery #13 which underwent environmental testing, the new cover and container was employed, utilizing additional height of separation over the plate tops, and the removal of all excess electrolyte was accomplished prior to final seal.

In looking at the results of the battery tests and the tear-down data exhibits, the main cause of battery failures is excess washing

and treeing of the negative active material over the tops of the separators to the positive lugs. This is due to the lack of height of the separators over the plates. Increasing the height of the separators over the plate tops is a design feature which, it is hoped, will prevent zinc growths in this direction. However, to accommodate the negative plate in this manner results in slightly higher cells, which increases battery weights, resulting in lower energy-to-weight ratios. Because of this the first 12 batteries were designed with minimum overhang of separation, allowing shorter cell height and resulting in lowest weight to give a 7.55 watt hr/lb. system that could deliver 500 two-hour cycles.

Redesign to provide more cell height to accommodate increased height of separation over the plate tops resulted in the prototype batteries, shipped, and battery #13 which underwent environmental testing of an energy yield of 7.4 watt hrs/lb. during the two-hour cycle. This is a reduction of approximately .15 watt hrs/lb. from the first design.

While it is hoped that negative material treeing over the tops of the separators can be eliminated in the redesign, this does not solve the problem of washing or shedding of the negative material. This can in many instances be controlled by the amount of free electrolyte remaining in cells after sealing. Additional study of binders is recommended. Battery #4, which contained polyethylene oxide as a negative material binder, resulted in excellent looking negative plates after some 370 cycles. There was considerable creeping of material around the separator folds, but this could have been due to excess electrolyte, since, in this case, it was believed necessary to use all the electrolyte possible to offset the built-in resistance of the negative plate caused by the binder material.

When a cell is newly activated, the current densities during charge and discharge are fairly evenly distributed between positive and negative

plates, providing separators are properly wet and have good conductive properties. As cycling advances, the negative material begins to wash causing an unbalance of current densities around both plates. Some areas of the negative plate thus commence to develop trees and dendrites, taking more current away from other areas of the plate. This can result in cells showing an open circuit voltage of anywhere from 1.53 to 1.85 volts, being unable to produce a satisfactory discharge because all portions of the positive and negative plates were not allowed to reform properly during the charge time. Furthermore, charging at this point becomes unsatisfactory because high end-of-charge voltages are developing leading to early gassing. For example, Table 18, Appendix III, shows charge and discharge voltages for battery #11 at about 87 cycles. It is observed that the end of charge voltages are safely below the gassing voltage of 2.0 volts and the end-of-discharge voltages are nearly the same, or at most, exhibit a difference of .01 volt. Now a comparison of this with Table 19, Appendix III, shows the charge and discharge voltages of this battery at 336 cycles. It is observed that several cells are charging at or over the gassing voltage of 2.00 volts, and the end-of-discharge voltages are becoming more scattered, most likely due to an increasingly rapid degradation of the negative plate.

It is believed that the new design of containers and covers, together with increased overhang of separation over the plate tops and removal of all excess electrolyte from the cell prior to sealing, will prolong the usable life of the negative plates incorporated in the final battery design.

APPENDIX I

SUPPORTING DATA FOR PART I

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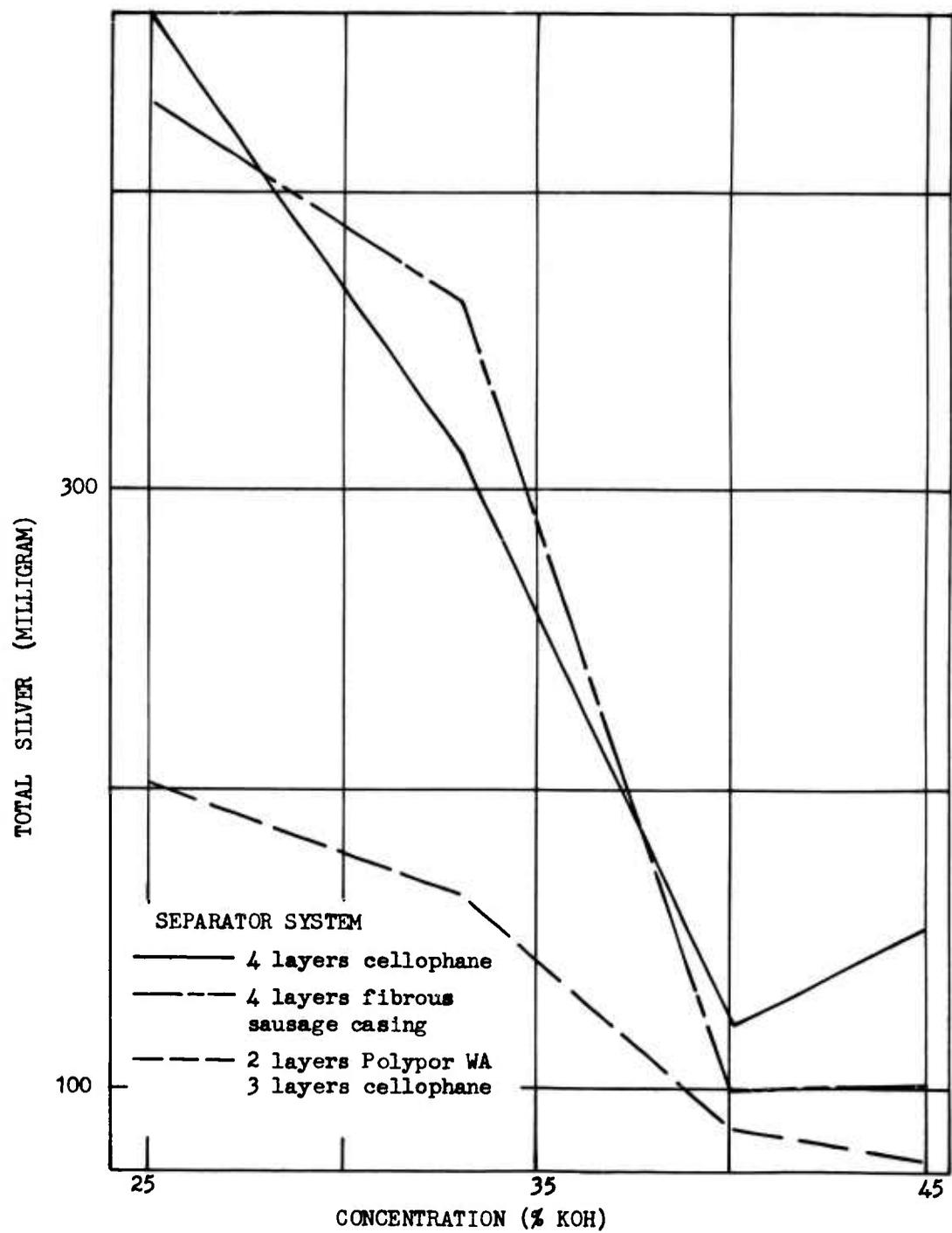
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TABLE 1

Silver Content of Various Separator Layers as a Function of Electrolyte and Number of Cycles

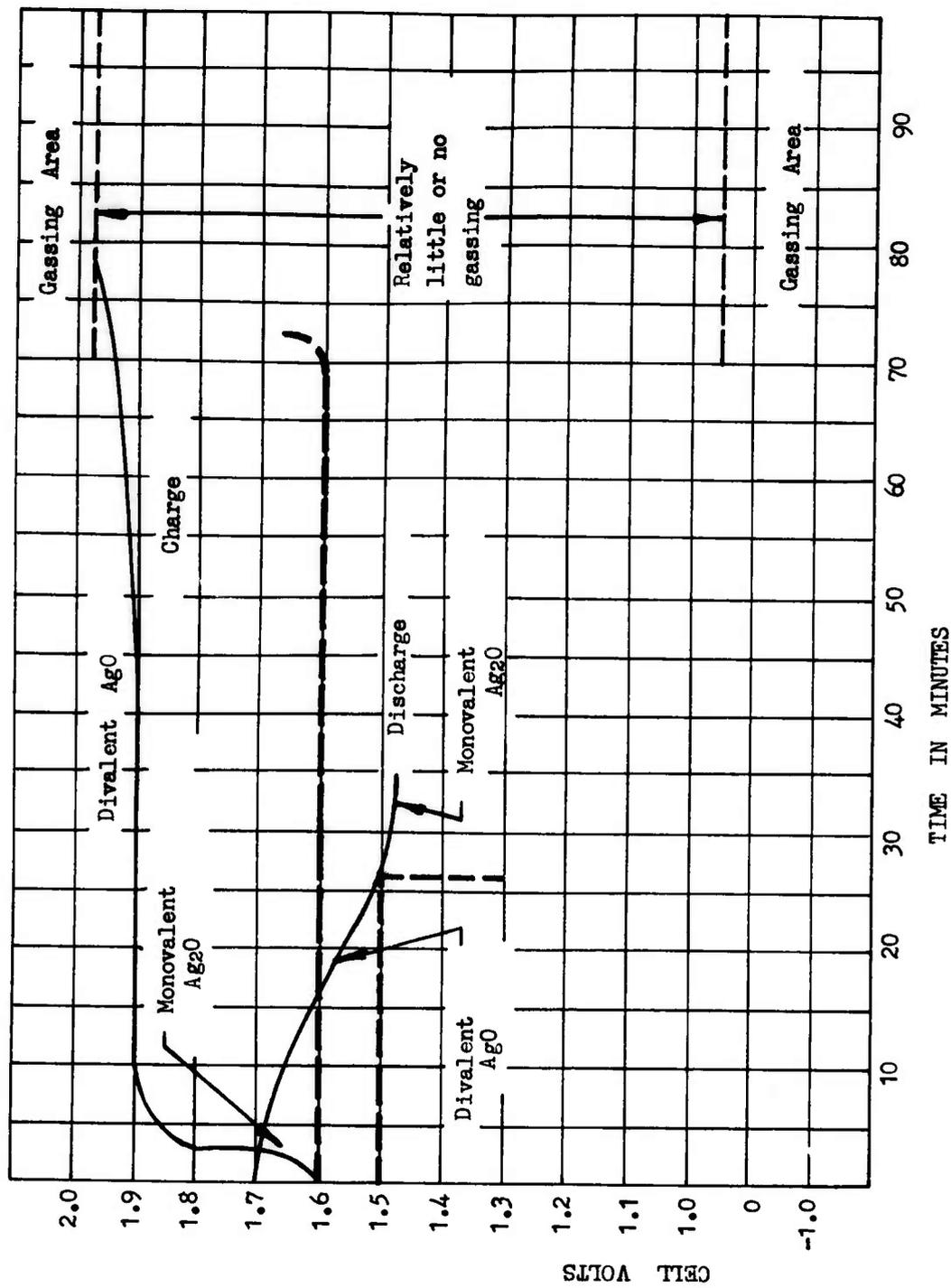
Cell	Layer (Mg.Ag/in <sup>2</sup> )					Total Ag (mg)	Cycle	Cell	No.	Layer (Mg.Ag/in <sup>2</sup> )					Total Ag (mg)	Cycle
	1	2	3	4	5					1	2	3	4	5		
1	42	-	-	-	-	120	5	61	33	-	-	-	-	-	198	5
6 cello	37	-	-	-	-	106	12	4 cello	62	0.4	-	-	-	-	90	13
33%	41	-	-	-	-	168	25	25%	63	0.2	-	-	-	-	177	25
KOH	49	-	-	-	-	229	98	R.T.	64	?	-	-	-	-	329	99
R.T.	84	1.2	-	-	-	312	275		65	1.7	0.7	0.1	-	-	460	280
6 FSC	20	-	-	-	-	89	5		66	24.6	-	-	-	-	148	5
33%	21	-	-	-	-	90	12	4 FSC	67	15.1	-	-	-	-	90	13
KOH	25	-	-	-	-	112	25	25%	68	21.6	-	-	-	-	172	25
R.T.	66	-	-	-	-	255	98	R.T.	69	71.3	0.3	-	-	-	430	99
	96	-	-	-	-	426	275		70	46.7	0.4	-	-	-	282	280
6 cello	33	-	-	-	-	125	5	2 poly	71	11.3	0.5	0.4	-	-	73	5
10%	27	-	-	-	-	134	13	3 cello	72	8.1	0.7	0.5	-	-	55	13
KOH	0.5	-	-	-	-	71	25		73	10.8	0.2	0.5	-	-	69	25
R.T.	27	5.4	0.7	-	-	143	97	25%	74	31.0	3.0	0.6	0.1	0.1	208	99
	27	4.0	0.8	0.4	-	165	120	R.T.	75	30.8	3.3	1.1	0.3	0.1	203	280
6 FSC	52	-	-	-	-	243	5		76	5.2	-	-	-	-	31	5
10%	42	-	-	-	-	209	13	4 cello	77	4.7	-	-	-	-	28	13
KOH	48	-	-	-	-	212	25	40%	78	5.3	-	-	-	-	32	25
R.T.	51	-	-	-	-	229	97	R.T.	79	13.1	0.4	-	-	-	81	100
	45	-	-	-	-	206	120		80	19.8	0.5	0.1	-	-	122	277
6 cello	15	-	-	-	-	87	5		81	7.5	-	-	-	-	45	5
33% unformed pes	8	-	-	-	-	45	13	4 FSC	82	8.0	-	-	-	-	48	13
R.T.	13	-	-	-	-	75	25	40%	83	6.5	-	-	-	-	39	25
	8	0.4	-	-	-	48	100	R.T.	84	18.1	-	-	-	-	109	100
	35	2.1	0.5	-	-	226	279		85	10.4	0.1	-	-	-	63	277
6 FSC	10	-	-	-	-	61	5		86	3.8	0.2	0.2	-	-	24	5
33%	10	-	-	-	-	62	13	2 poly	87	1.7	0.2	0.3	-	-	13	13
	15	-	-	-	-	87	25	3 cello	88							

R.T.	25	35	2.1	0.5	-	-	226	279	85	10.4	0.1	-	-	63	277
6 FSC	26	10	-	-	-	-	61	5	86	3.8	0.2	0.2	-	24	5
33% unformed pcs	27	10	-	-	-	-	62	13	87	1.7	0.2	0.3	-	13	13
R.T.	28	15	-	-	-	-	87	25	88	4.3	0.1	0.3	-	28	25
	29	22	-	-	-	-	134	100	89	9.9	0.5	0.5	0.4	68	100
	30	48	0.5	-	-	-	291	279	90	12.0	1.5	1.1	0.1	88	277
	31	1.5	0.3	0.2	0.3	-	14	5	91	12.8	0.4	-	-	79	5
4 poly	32	2.0	0.3	0.3	0.3	-	18	13	92	12.0	-	-	-	72	13
33%	33	2.6	0.5	0.2	0.5	-	23	25	93	13.2	0.1	-	-	80	25
R.T.	34	3.6	1.2	sample lost	0.7	-	34	99	94	14.3	0.3	-	-	88	100
	35	7.2	2.3	1.1	1.2	-	71	279	95	24.0	1.5	0.2	-	154	277
1 poly	36	12.5	2.0	-	-	-	86	5	96	14.0	-	-	-	84	5
1 cello	37	12.0	2.0	-	-	-	86	13	97	14.7	-	-	-	88	13
1 EM 387	38	13.6	1.8	-	-	-	93	25	98	14.5	-	-	-	87	25
33%	39	16.2	3.4	VST	-	-	117	99	99	14.3	-	-	-	86	100
R.T.	40	46.9	4.1	0.4	-	-	308	279	100	16.9	0.2	-	-	102	277
	41	25.5	-	-	-	-	153	5	101	8.1	0.5	0.7	-	56	5
6 heavy cello	42	6.8	-	-	-	-	41	13	102	7.4	0.8	0.2	-	50	13
33%	43	8.4	-	-	-	-	51	25	103	7.4	0.3	0.1	-	47	25
R.T.	44	11.4	VST	-	-	-	68	100	104	11.3	0.7	0.2	-	73	100
	45	-	9.8	-	-	-	59	279	105	9.3	2.0	0.8	0.4	77	277
2 poly	46	7.2	VST	-	-	-	43	5	106	10.6	0.5	0.2	0.1	68	5
3 cello	47	4.3	-	-	-	-	26	14	107	11.1	0.3	0.1	0.1	71	13
33%	48	4.5	VST	-	-	-	27	26	108	14.0	0.5	0.3	0.3	92	25
R.T.	49	11.8	0.2	-	-	-	71	100	109	35.9	1.0	0.2	0.2	225	100
	50	22.8	2.4	1.6	0.4	0.5	166	295	110	-	-	-	-	-	-
	51	3.6	VST	-	-	-	22	5	111	23.8	0.4	0.3	0.2	148	5
2 poly	52	6.5	VST	-	-	-	39	13	112	23.5	0.8	0.4	0.3	52	52
2 FSC	53	6.6	VVST	-	-	-	40	25	113	18.8	1.1	0.7	0.5	255	255
33%	54	13.5	0.5	0.1	-	-	85	100	114	15.9	0.5	0.1	0.1	100	13
R.T.	55	23.0	5.2	0.5	0.2	-	173	280	115	21.6	0.8	0.4	0.2	52	52
	56	4.7	5.0	0.2	-	-	59	5	116	27.1	1.5	0.7	0.5	255	255
1 EM 387	57	1.6	3.5	0.4	0.2	-	30	13							
2 poly	58	1.6	1.5	0.2	0.1	-	11	25							
2 cello	59	3.0	15.0	5.0	1.3	0.3	145	99							
33%	60	1.3	21.3	3.1	0.9	0.2	162	280							
R.T.															



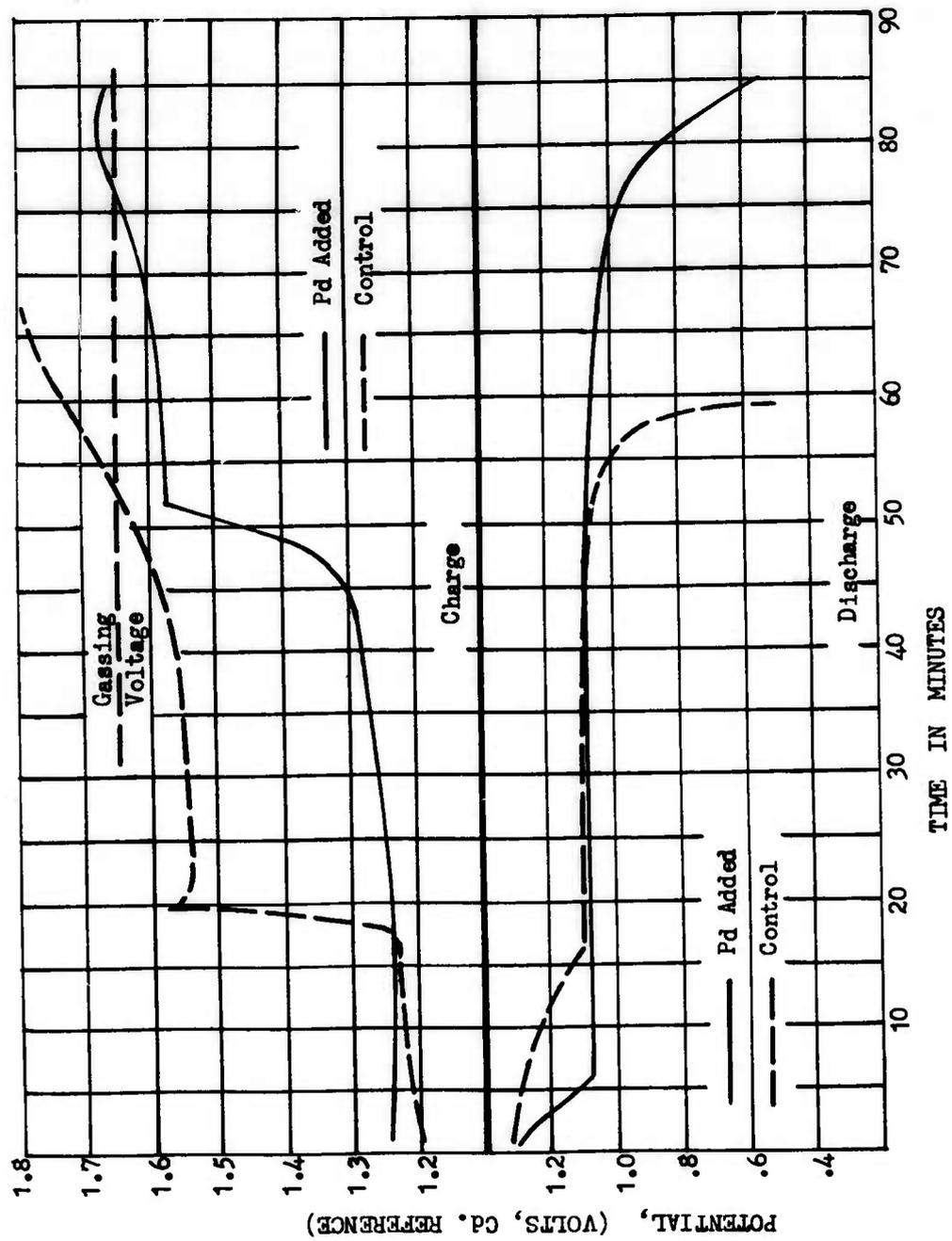
TOTAL SILVER CONTENT OF SEPARATOR AFTER 275 CYCLES AS A FUNCTION OF KOH CONCENTRATION

FIGURE 1



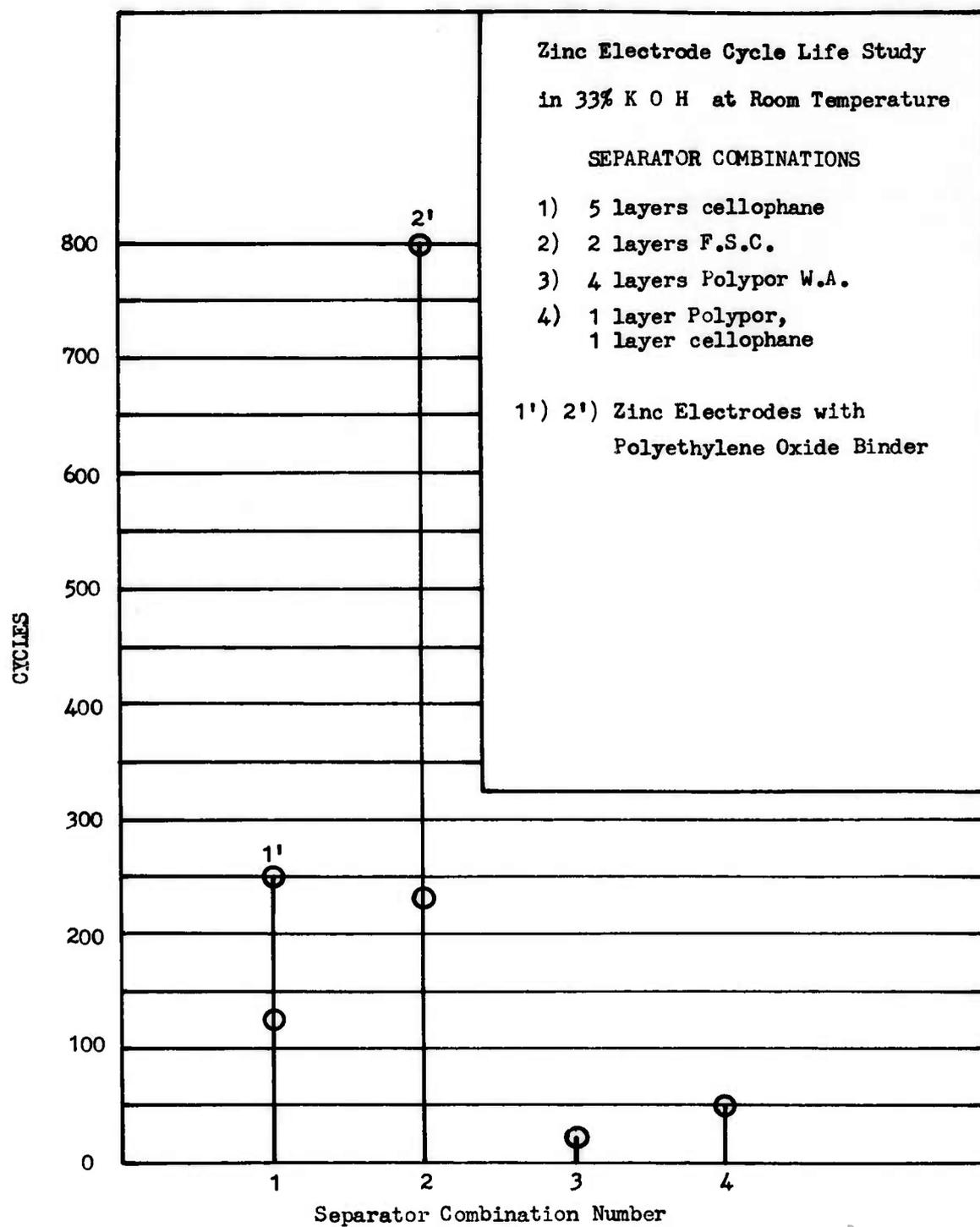
TYPICAL CHARGE - DISCHARGE CURVE, 2 HR. CYCLE

FIGURE 2



EFFECT OF PALLADIUM ADDITIONS ON POSITIVE PLATE PERFORMANCE

FIGURE 3



ZINC ELECTRODE CYCLE LIFE

FIGURE 4

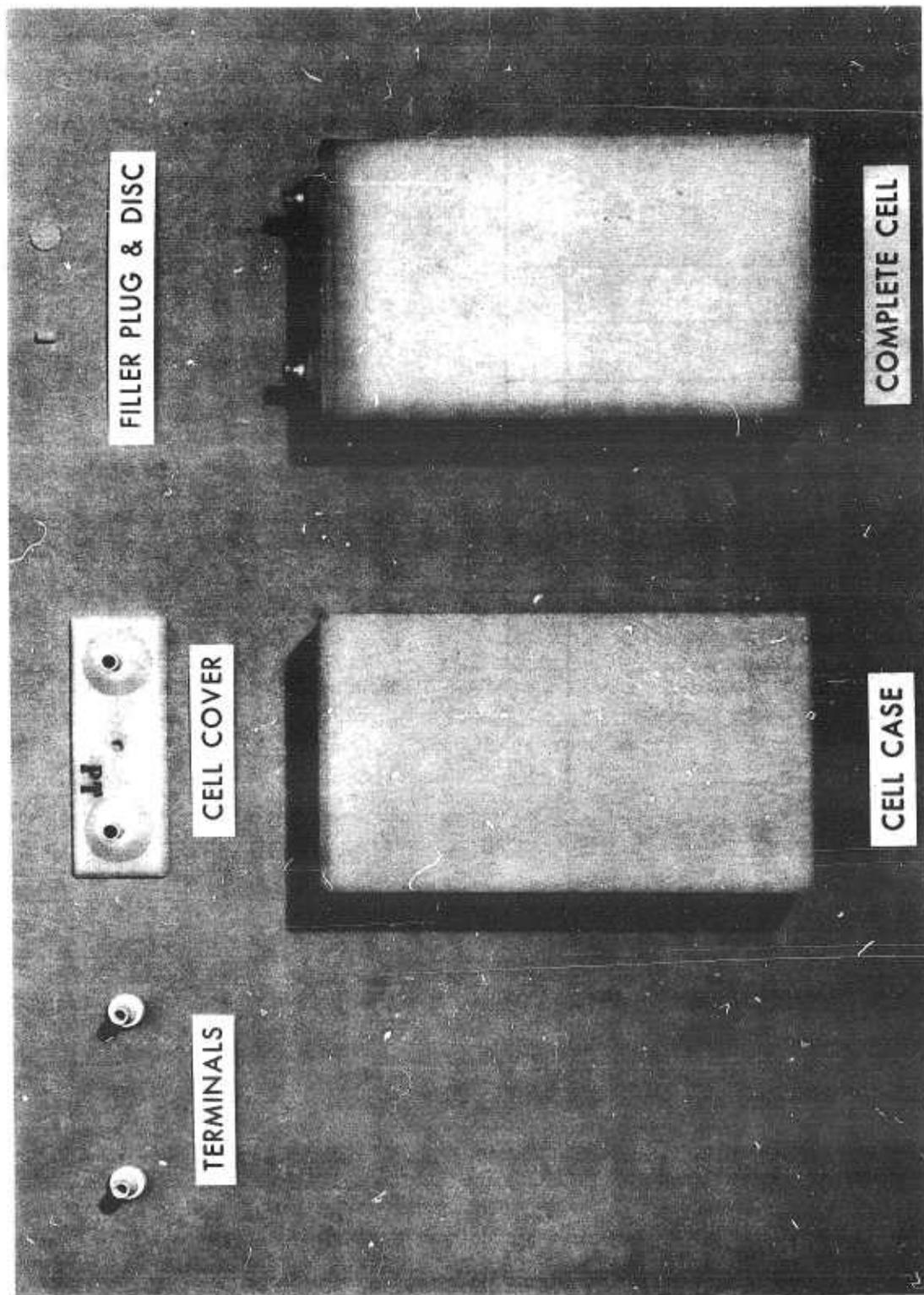


Figure 5. Terminal and Molded Parts of the Cell

APPENDIX II

SUPPORTING DATA FOR PART II

## TEST SUMMARY SHEET 1

TEST COMPLETION OCTOBER, 1961

48 a.h. Cells A, B, C Contain .010" Positive Plates; Remaining 25 a.h. Cells Contain .020" Positive Plates. All Cells Activated in 40% KOH - Zincate

Cell #	Cycles	Cycle Temp.	Current Density	% Depth Discharge	Separators	Negative Plate Process	Cause of Failure	Cell #
A	1760	R.T.	.043 a/in <sup>2</sup>	21%	5 layers FSC	ZnO + 1% HgO Mix	Corrosion of Positive Plate Lugs	A
B	1760	"	"	"	"	"	"	B
C	1760	"	"	"	"	"	"	C
1	297	"	.070 a/in <sup>2</sup>	"	2 layers FSC	ZnO + 1% HgO Mix	Shorts - silver migration through separators	1
2	442	"	"	"	"	.040"	"	2
3	380	"	"	"	"	"	"	3
4	704	"	"	"	4 layers cellophane	"	"	4
5	310	"	"	"	"	"	Ruptured Container	5
6	962	"	"	"	"	"	Shorts - silver migration through separators	6
7	442	"	"	"	3 layers FSC	"	Ruptured Container	7
8	637	"	"	"	"	"	Excessive washing of negative material	8
9	192	"	"	"	"	"	Ruptured Container	9
10	442	"	"	"	6 layers cellophane	"	"	10
11	442	"	"	"	"	"	"	11
12	649	"	"	"	"	"	Shorts - silver penetration	12
13	380	"	"	"	2 layers FSC	ZnO + 1% HgO + Polyethylene Oxide Mix	Ruptured Container	13
14	86	"	"	"	"	"	"	14
15	720	"	"	"	"	"	Shorts - silver penetration	15
16	382	"	"	"	2 layers FSC	ZnO + 1% HgO + Solka Floc Mix	"	16
17	297	"	"	"	"	"	"	17
18	297	"	"	"	"	"	"	18
19	555	"	"	"	2 layers FSC	ZnO + 1% HgO + PVA Mix	"	19
20	600	"	"	"	"	"	"	20
21	637	"	"	"	"	"	"	21
22	480	"	"	"	1 layer Dynel, 2 layers FSC	ZnO + 1% HgO Mix	Excessive washing of negative material	22
23	100	"	"	"	"	"	Ruptured container	23
24	543	"	"	"	"	"	Excessive washing of negative material	24
25	703	"	"	"	1 layer Dynel, 3 layers FSC	"	"	25
26	100	"	"	"	"	"	Ruptured Container	26
27	703	"	"	"	"	"	Excessive washing of negative material	27
28	466	"	"	"	1 layer Dynel, 1 layer Polypor, 3 layers FSC	"	"	28
29	465	"	"	"	"	"	"	29
30	551	"	"	"	"	"	"	30
31	583	100°F	"	"	"	"	"	31
32	415	"	"	"	"	"	"	32
33	574	"	"	"	"	"	"	33

## TEST SUMMARY SHEET 2

TEST COMPLETION OCTOBER, 1961

All Cells Containing .020" Positive Plates Activated in 40% KOH - Zincate

Cell #	Cycles	Cycle Temp.	Current Density	% Depth Discharge	Separators	Negative Plate Process	a.h. Cap.	Cause of Failure	Cell #
34	200	30° F.	.070 a/in <sup>2</sup>	21%	1 layer Dynel, 1 layer Polyper, 3 layers FSC	ZnO + 1% HgO Mix .040"	25	Cells unable to accept recharge	34
35	200	"	"	"	"	"	"	"	35
36	122	"	"	"	"	"	"	"	36
37	302	R.T.	.095 a/in <sup>2</sup>	29%	"	"	18	Excessive washing of negative material	37
38	344	"	"	"	"	"	"	"	38
39	302	"	"	"	"	"	"	"	39
40	400	100° F.	"	"	"	"	"	"	40
41	368	"	"	"	"	"	"	"	41
42	302	"	"	"	"	"	"	Ruptured container	42
43	122	30° F.	"	"	"	"	"	Cells unable to accept recharge	43
44	122	"	"	"	"	"	"	"	44
45	122	"	"	"	"	"	"	"	45
46	200	R.T.	.125 a/in <sup>2</sup>	40.5%	"	"	13	Excessive washing of negative material	46
47	200	"	"	"	"	"	"	"	47
48	200	"	"	"	"	"	"	"	48
49	200	100° F.	"	"	"	"	"	"	49
50	200	"	"	"	"	"	"	"	50
51	200	"	"	"	"	"	"	"	51
52	47	30° F.	"	"	"	"	"	Cells unable to accept recharge	52
53	47	"	"	"	"	"	"	"	53
54	47	"	"	"	"	"	"	"	54
55	152	R.T.	.070 a/in <sup>2</sup>	21%	2 layers FSC	ZnO + 1% HgO Polyethylene Oxide Mix	25	Dry cells	55
56	152	"	"	"	"	"	"	"	56
57	462	"	"	"	1 layer Dynel, 3 layers FSC	ZnO + 1% HgO Mix	"	Excessive washing of negative material	57
58	547	"	"	"	"	"	"	Ruptured containers	58
59	400	"	"	"	1 layer polyethylene base 3 layers FSC	ZnO + 1% HgO mix	"	"	59
60	560	"	"	"	"	"	"	"	60
61	560	"	"	"	"	"	"	"	61
62	4	"	"	"	"	"	"	"	62
63	856	"	"	"	1 layer Dynel, 4 layers FSC	ZnO + 1% HgO, PVA Mix	"	Cracked case on bottom edge	63
64	873	"	"	"	"	"	"	"	64
65	603	"	"	"	"	"	"	"	65
66	873	"	"	"	"	"	"	"	66
67	856	"	"	"	"	"	"	"	67
68	658	"	"	"	"	"	"	"	68

1

TEST SUMMARY SHEET 3 TEST NOT COMP

All Cells Activated in 40% KOH - Zinca

Cell #	Cycles	Cycle Temp.	a.h. Cap.	Current Density	% Depth Discharge	Separators	Ne
69	873	R.T.	25	.070 a/in <sup>2</sup>	21%	1 layer Dynel, 4 layers FSC	ZnO +
70	658	"	"	"	"	"	"
71	513	"	"	"	"	"	ZnO +
72	661	"	"	"	"	"	ZnO, N
73	432	"	"	"	"	"	"
74	400	"	"	"	"	"	"
75	515	"	"	"	"	"	"
76	408	"	"	"	"	"	"
77	465	"	"	"	"	"	"
78	608	"	"	"	"	"	"
79	870	"	37	.052 a/in <sup>2</sup>	24%	1 layer Dynel, 3 layers FSC	ZnO + 1
80	90	"	"	"	"	"	.020" r
81	300	"	"	"	"	"	"
82	857	"	"	"	"	"	ZnO + 1
83	340	"	"	"	"	1 layer polyethylene base	"
84	454	"	"	"	"	3 layers FSC	"
85	837	"	"	"	"	"	"
86	588	"	"	"	"	"	ZnO + 1

HEET 3 TEST NOT COMPLETED

ated in 40% KOH - Zincate

rators	Negative Plate Process	Status	Cell #
Dynel, 4 SC	ZnO + 1% HgO with PVA in mix	Cracked case on bottom edge	69
	"	"	70
	ZnO + 1% HgO with excess ZnO, No PVA	"	71
	"	"	72
	"	"	73
	"	"	74
	"	"	75
	"	"	76
	"	"	77
	"	"	78
Dynel, 3 SC	ZnO + 1% HgO .010" positive .020" negative	Zn bridged on top of seps to pos. terminal	79
	"	Broken case	80
	ZnO + 1% HgO with PVA in mix	Shorts, Zn treeing to positive	81
	"	Shorts through separator	82
polyethylene base FSC	"	Shorts	83
	"	Zn treeing to pos. terminal	84
	ZnO + 1% HgO	Shorts through separator	85
	"	Shorts, washing of negative material.	86

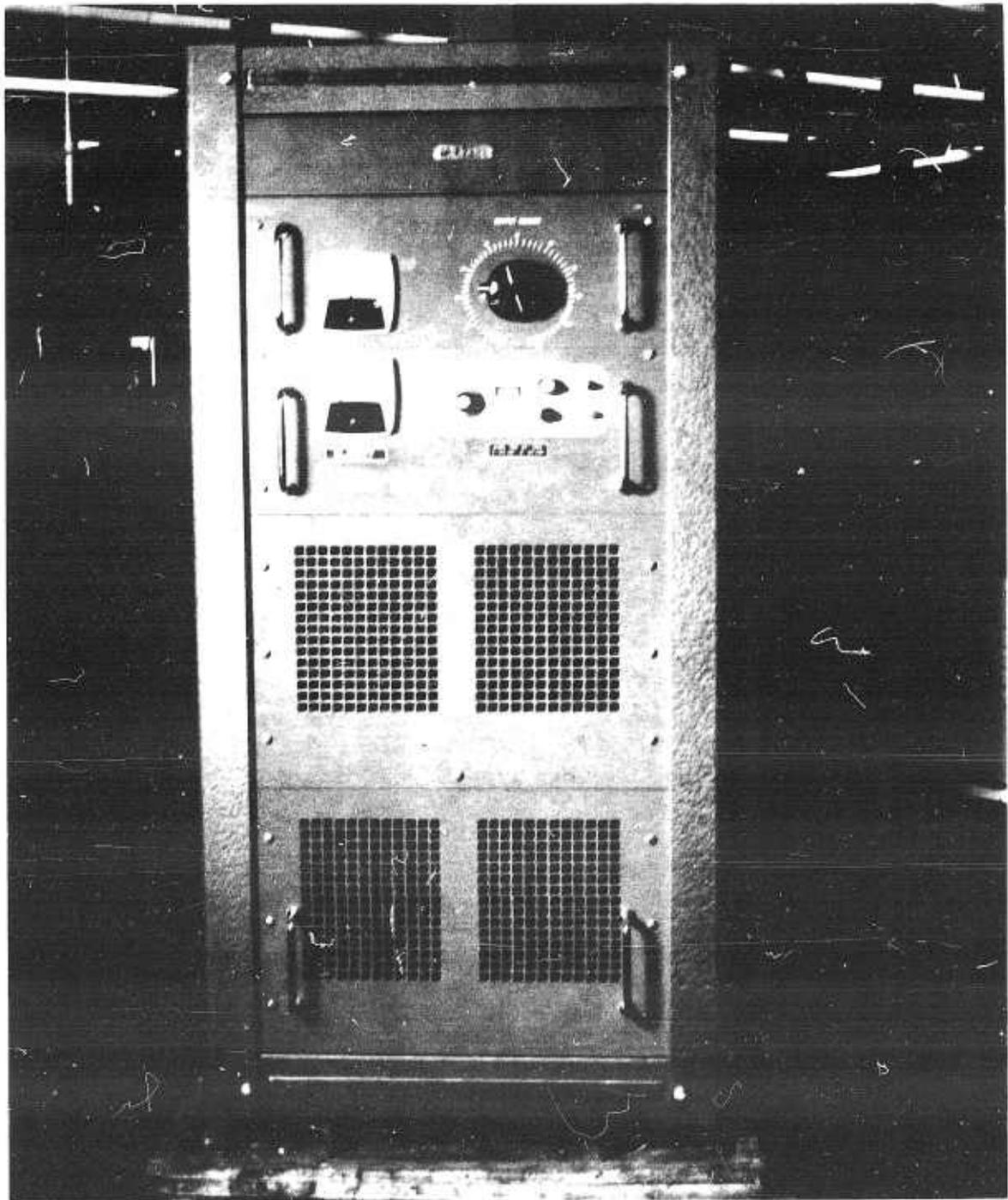
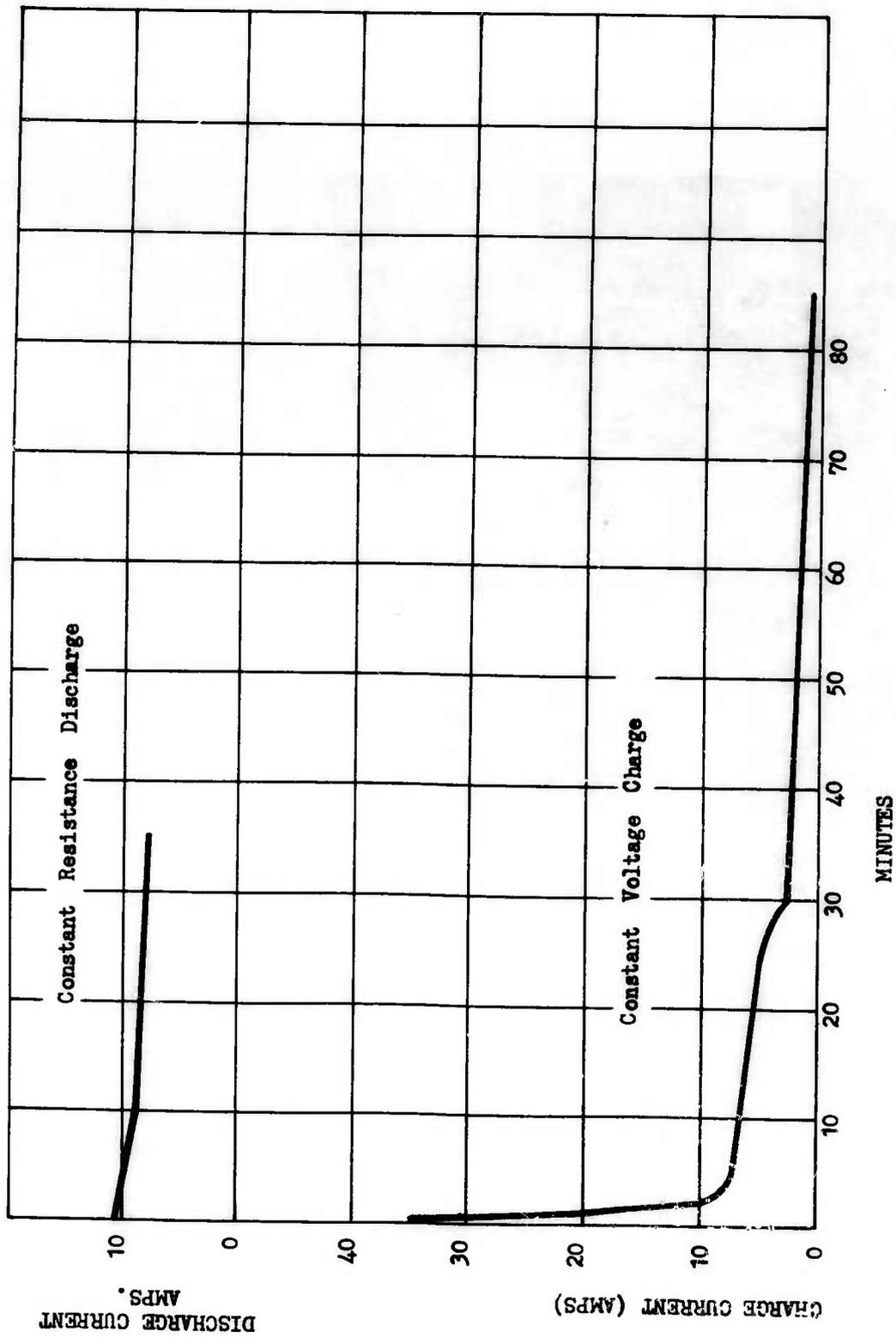


Figure 6. Constant Potential Power Supply Unit

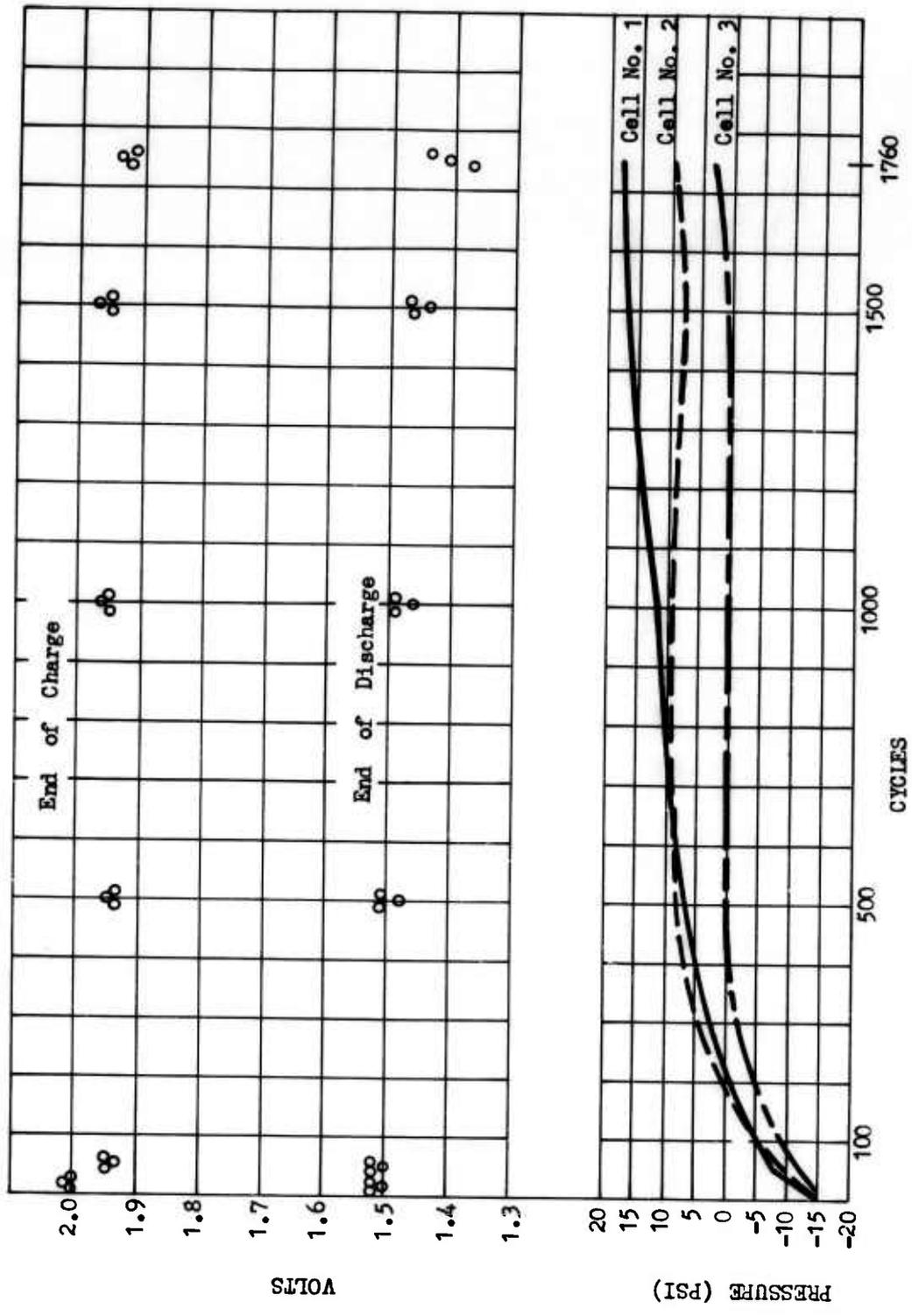


Figure 7. Recording Voltmeter, Battery Timer and Cells Undergoing Cycle Life



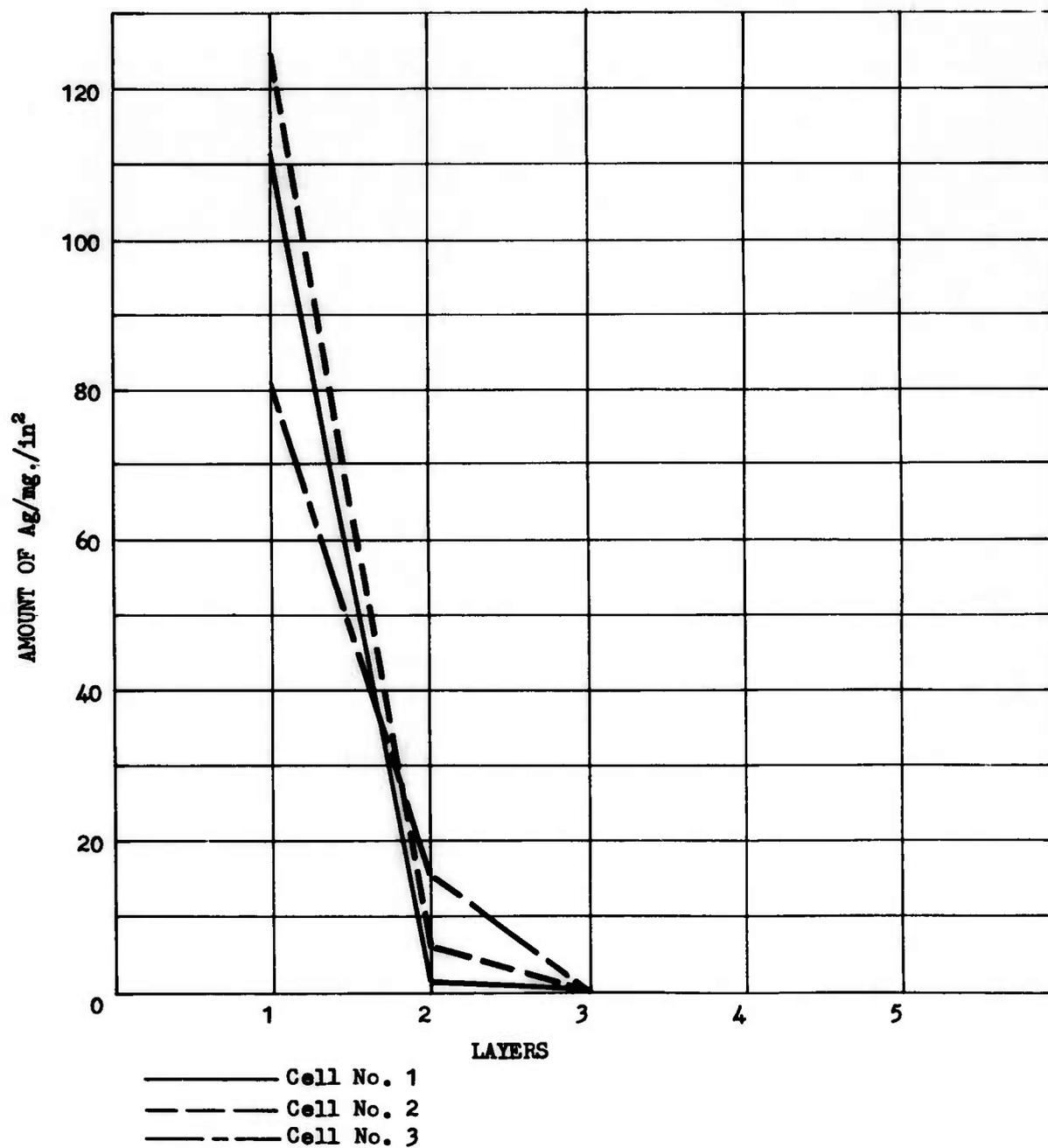
TYPICAL CHARGE AND DISCHARGE CURVE OF CURRENT FOR CELLS IN GROUP I, II, III, IV.

FIGURE 8



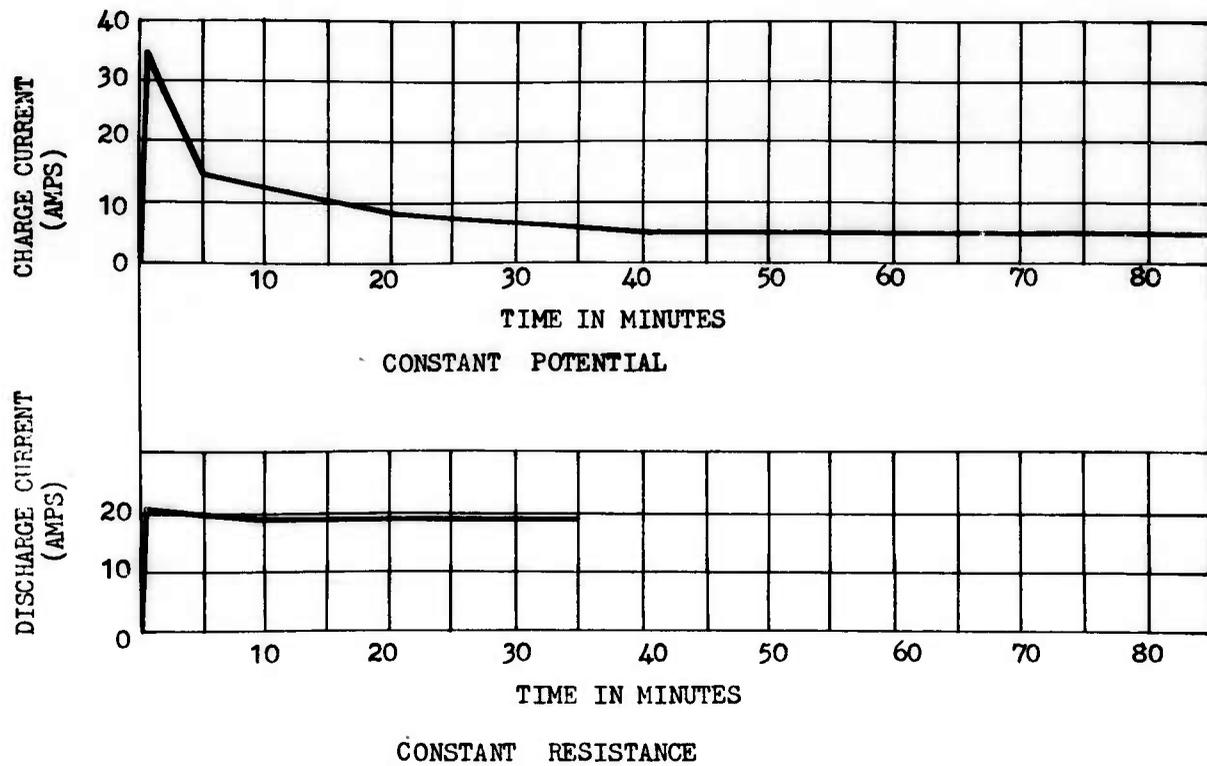
END OF CHARGE VOLTAGE      END OF DISCHARGE  
 VOLTAGE AND PRESSURE FOR SEALED BATTERY OF 3 CELLS.      POINTS, READING FROM LEFT TO  
 RIGHT, INDICATE CELLS NO. 1, 2, 3, RESPECTIVELY

FIGURE 9



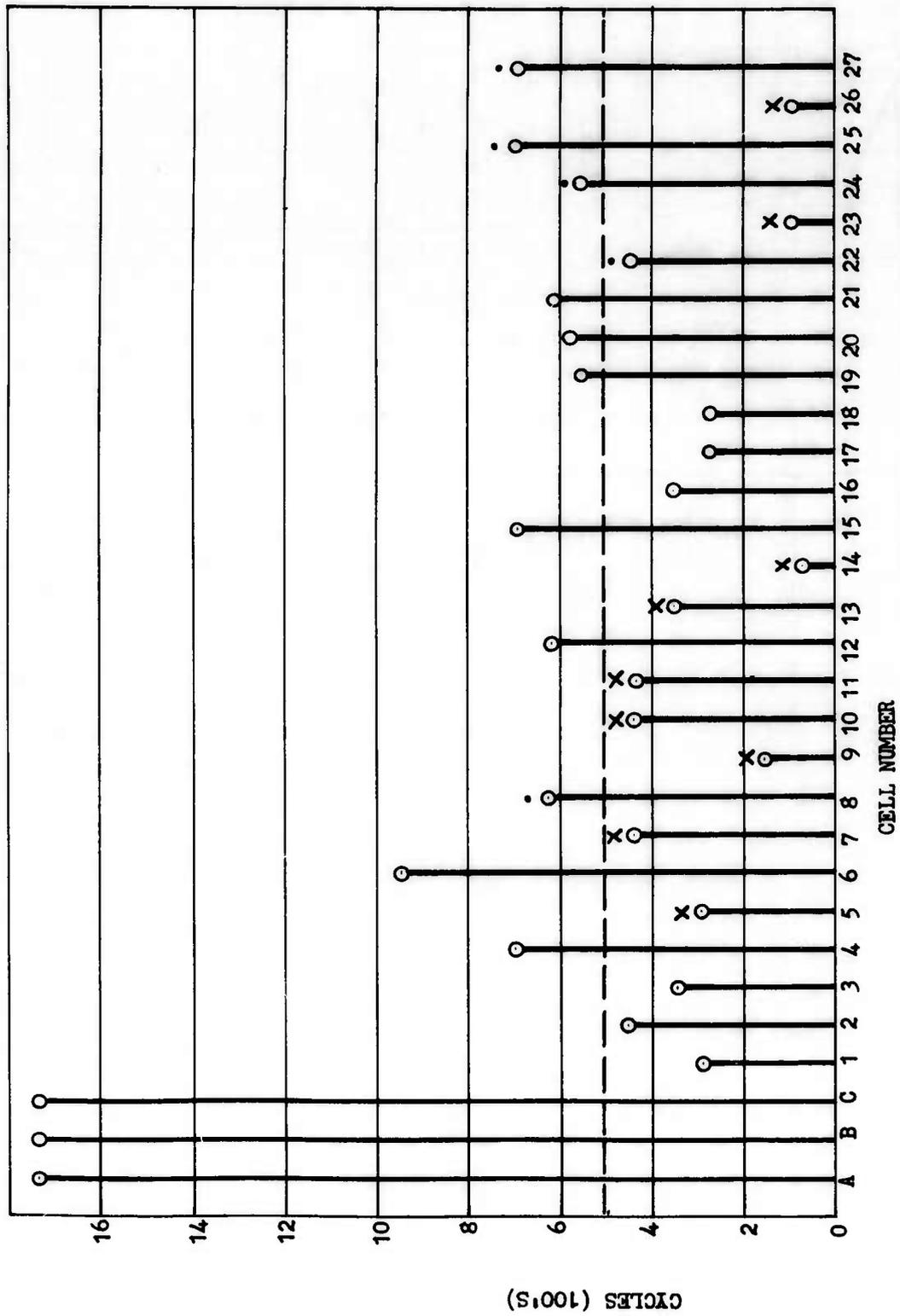
SILVER CONTENT IN SEPARATORS AFTER 1760 CYCLES IN EACH OF THREE CELLS

FIGURE 10



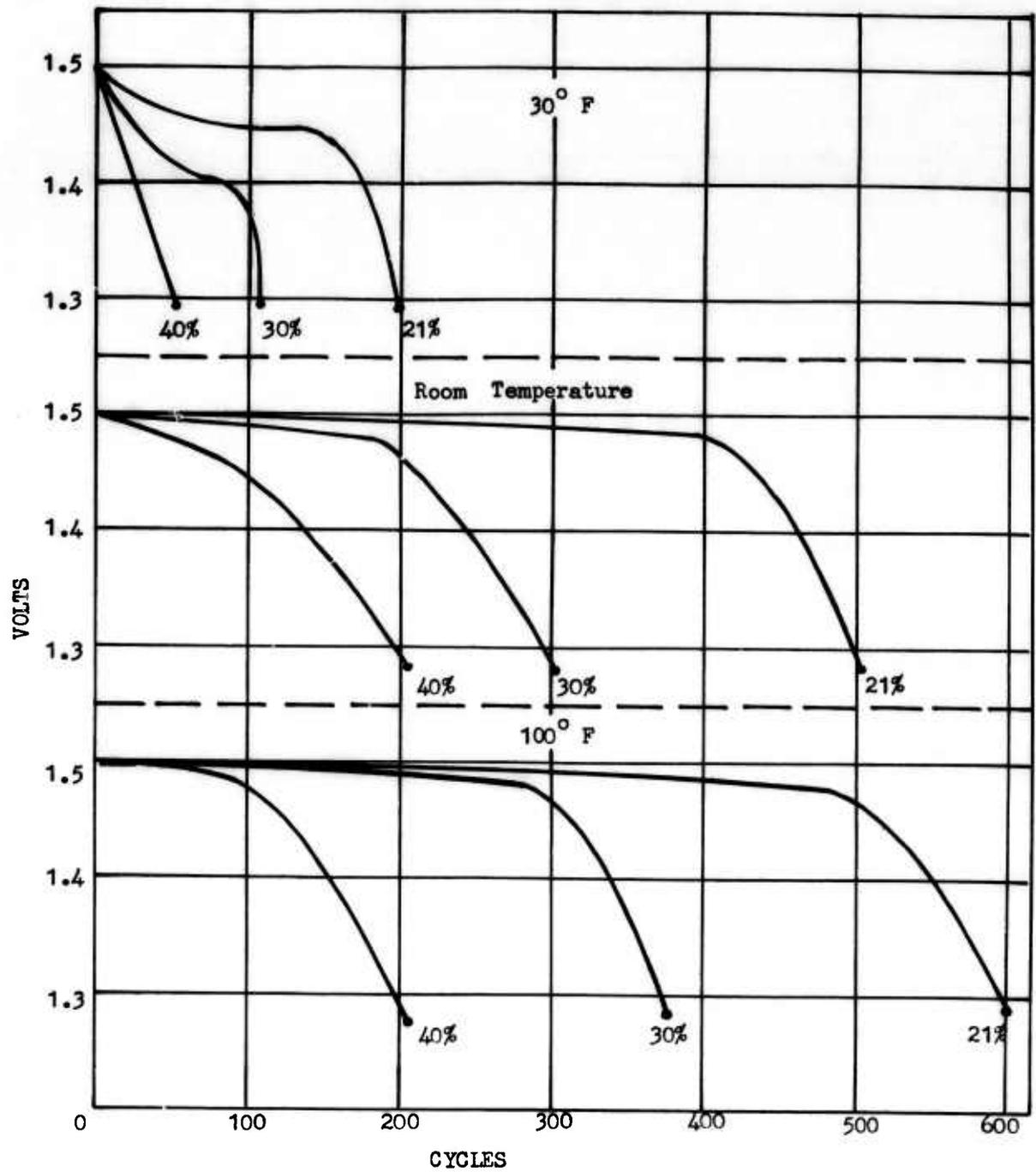
TYPICAL CHARGE AND DISCHARGE CURVE OF CURRENT OPERATING  
FOR 1760 CYCLES

FIGURE 11



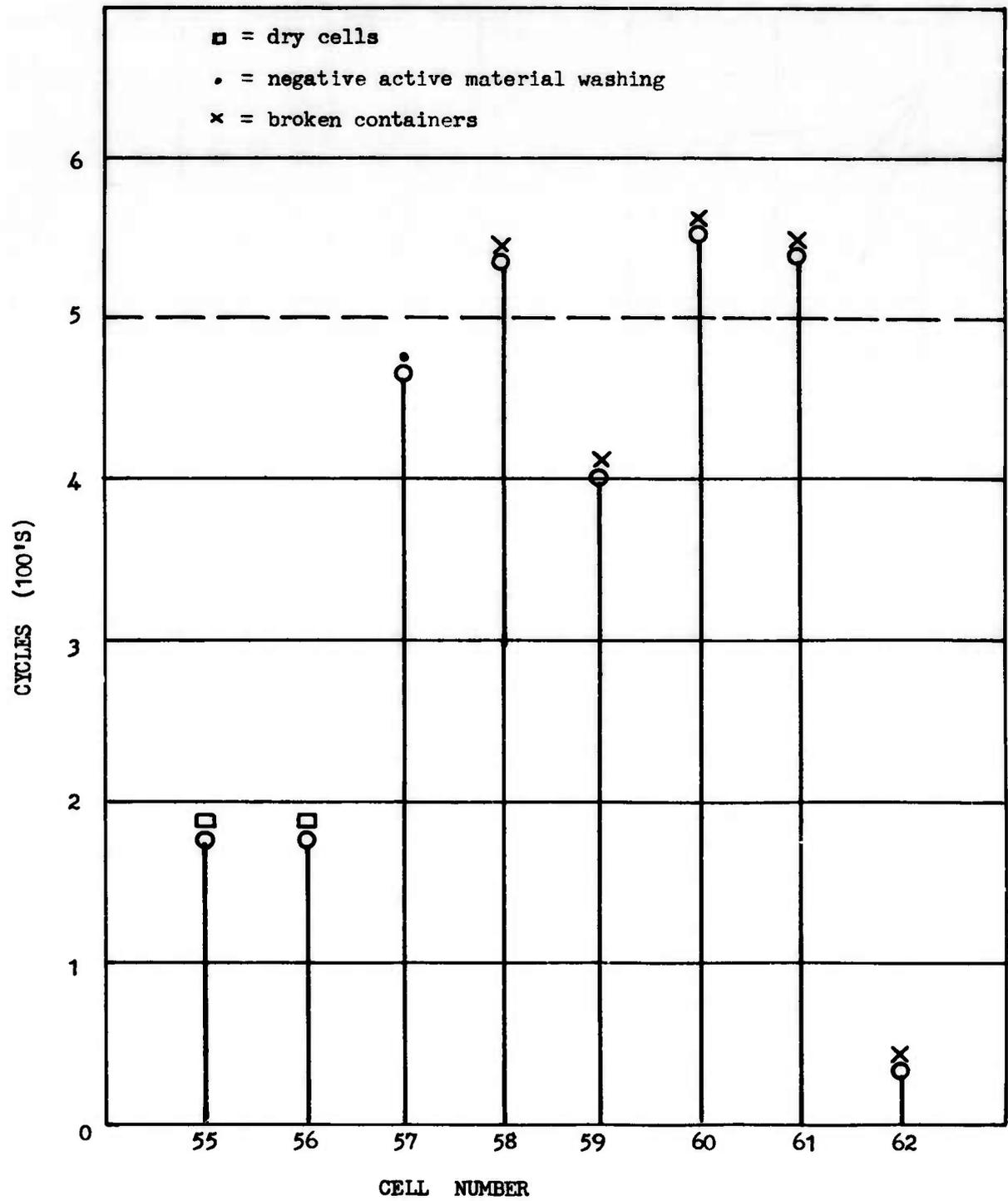
NUMBER OF CYCLES OBTAINED BY GROUP 1 CELLS

FIGURE 12



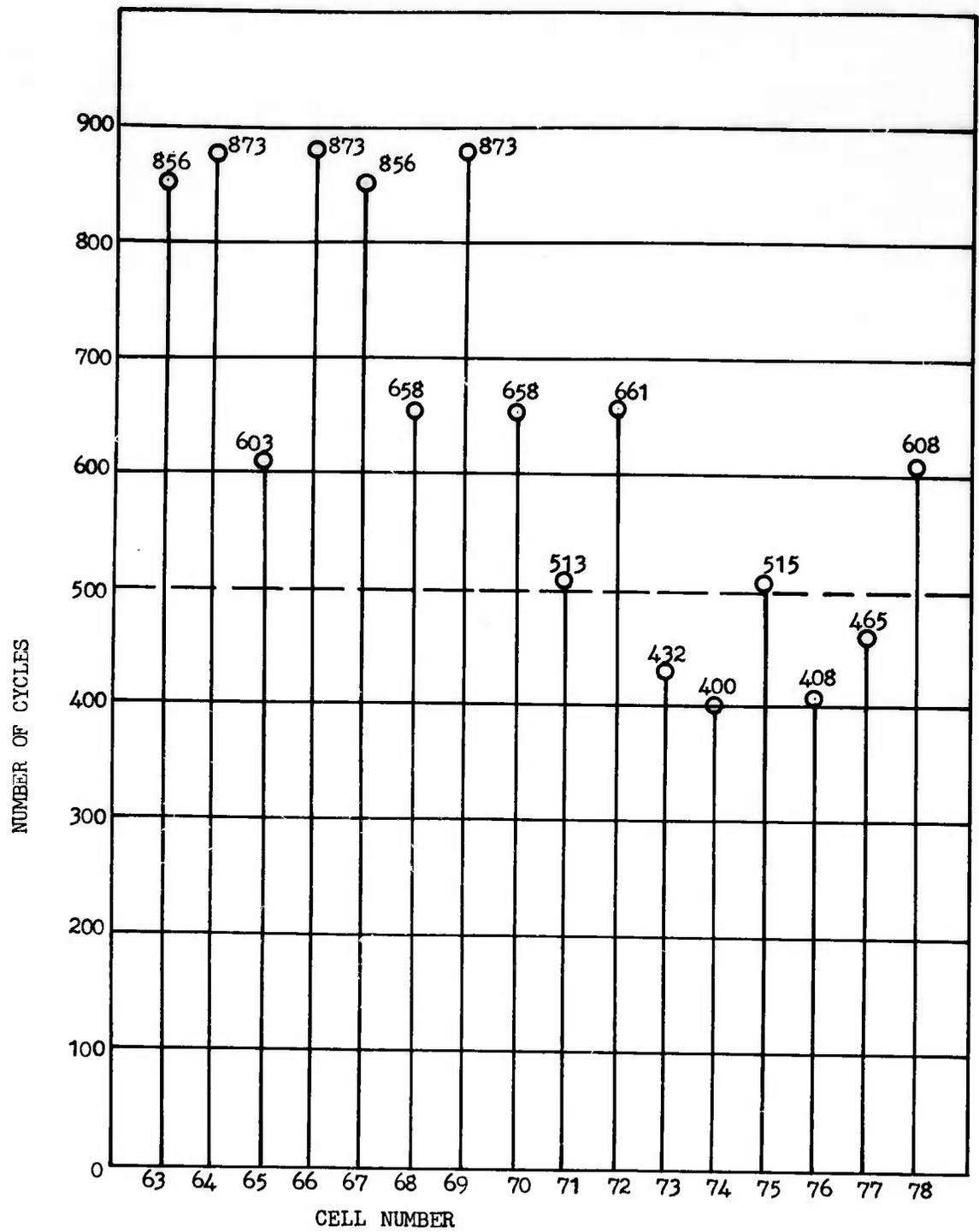
END OF DISCHARGE VOLTAGES AT EACH 100 CYCLE INTERVAL FOR THE INDICATED TEMPERATURES AND DEPTHS OF DISCHARGES .

FIGURE 13



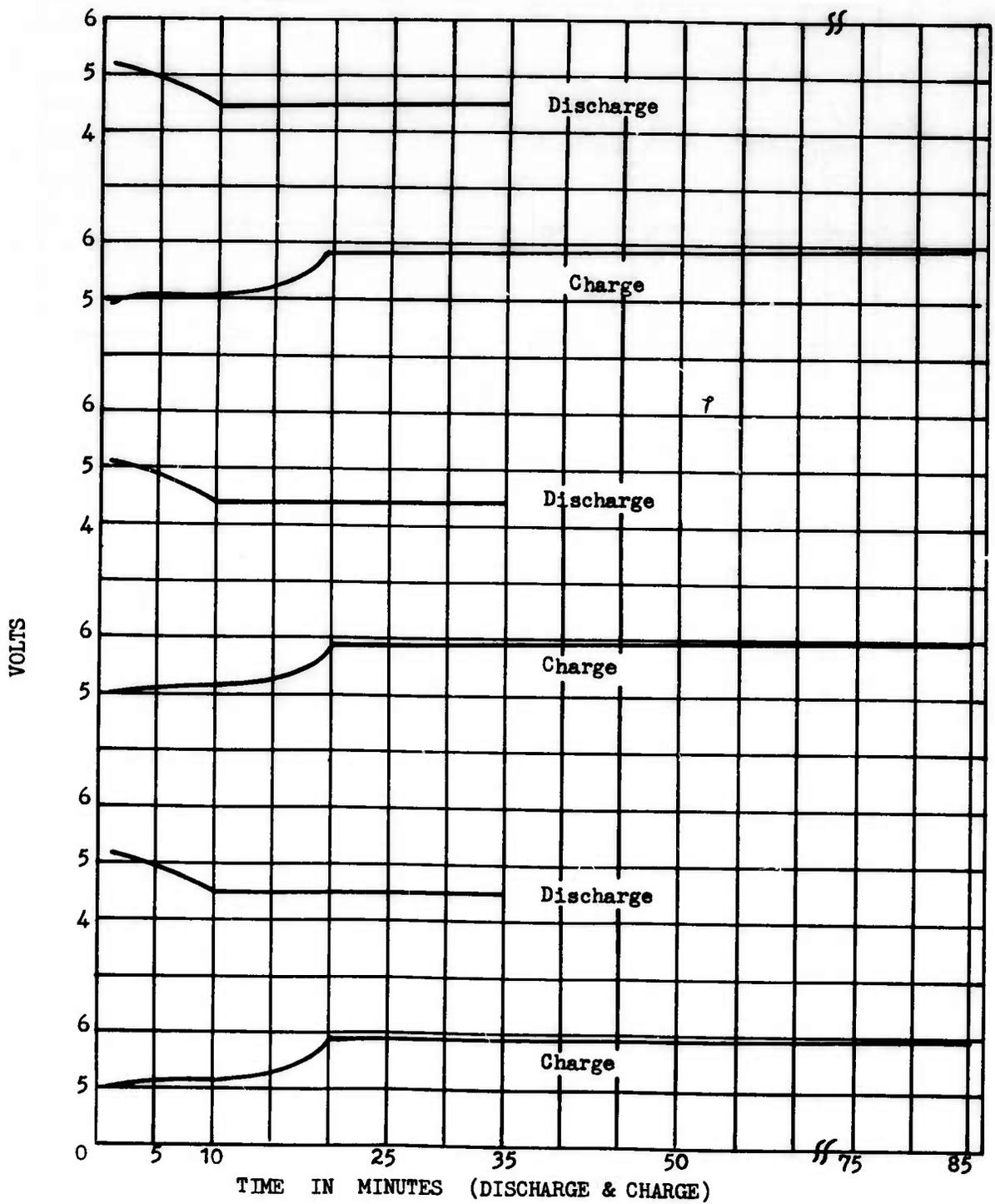
NUMBER OF CYCLES OBTAINED BY GROUP 3 CELLS

FIGURE 14



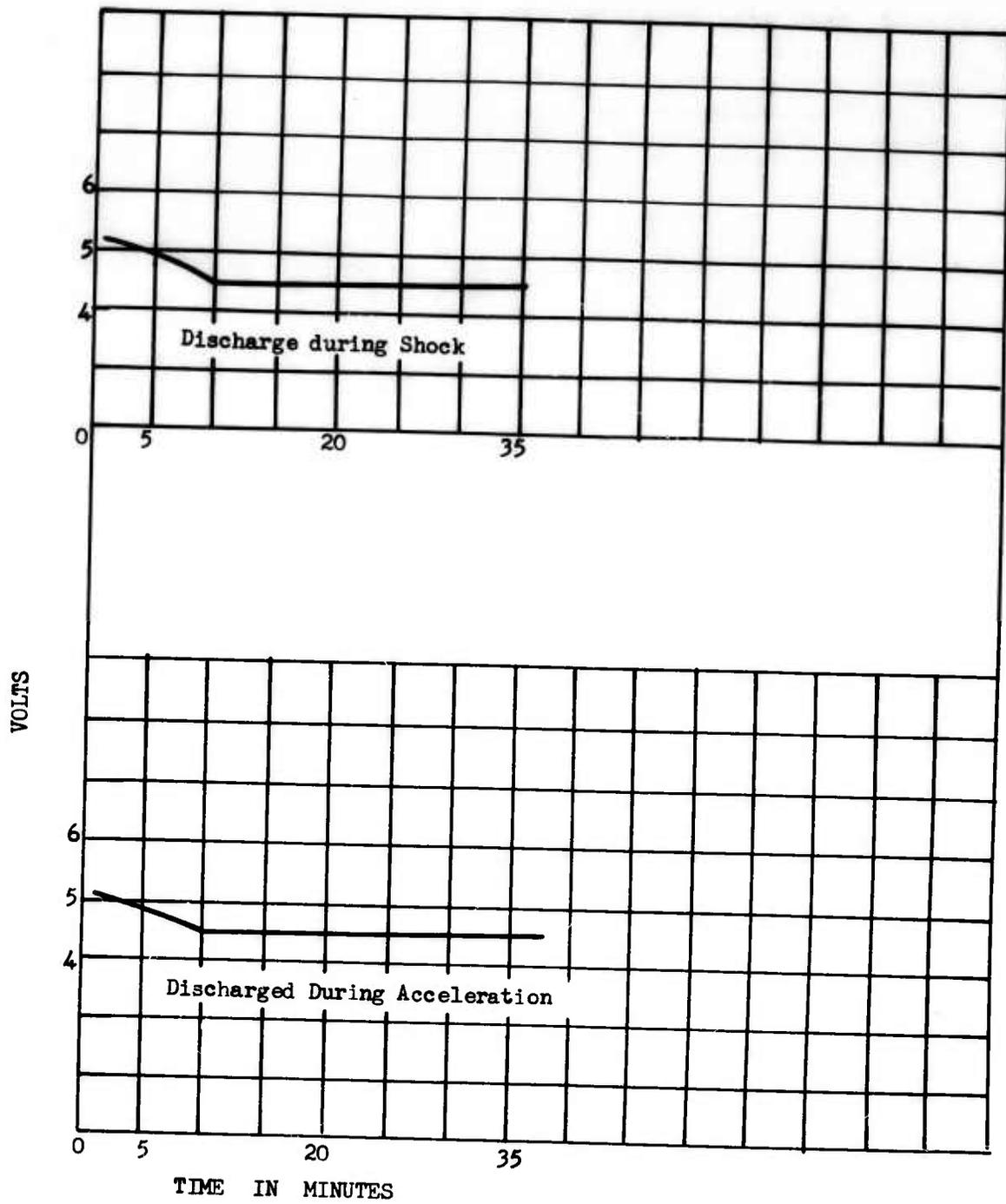
NUMBER OF CYCLES OBTAINED BY GROUP 4 CELLS

FIGURE 15



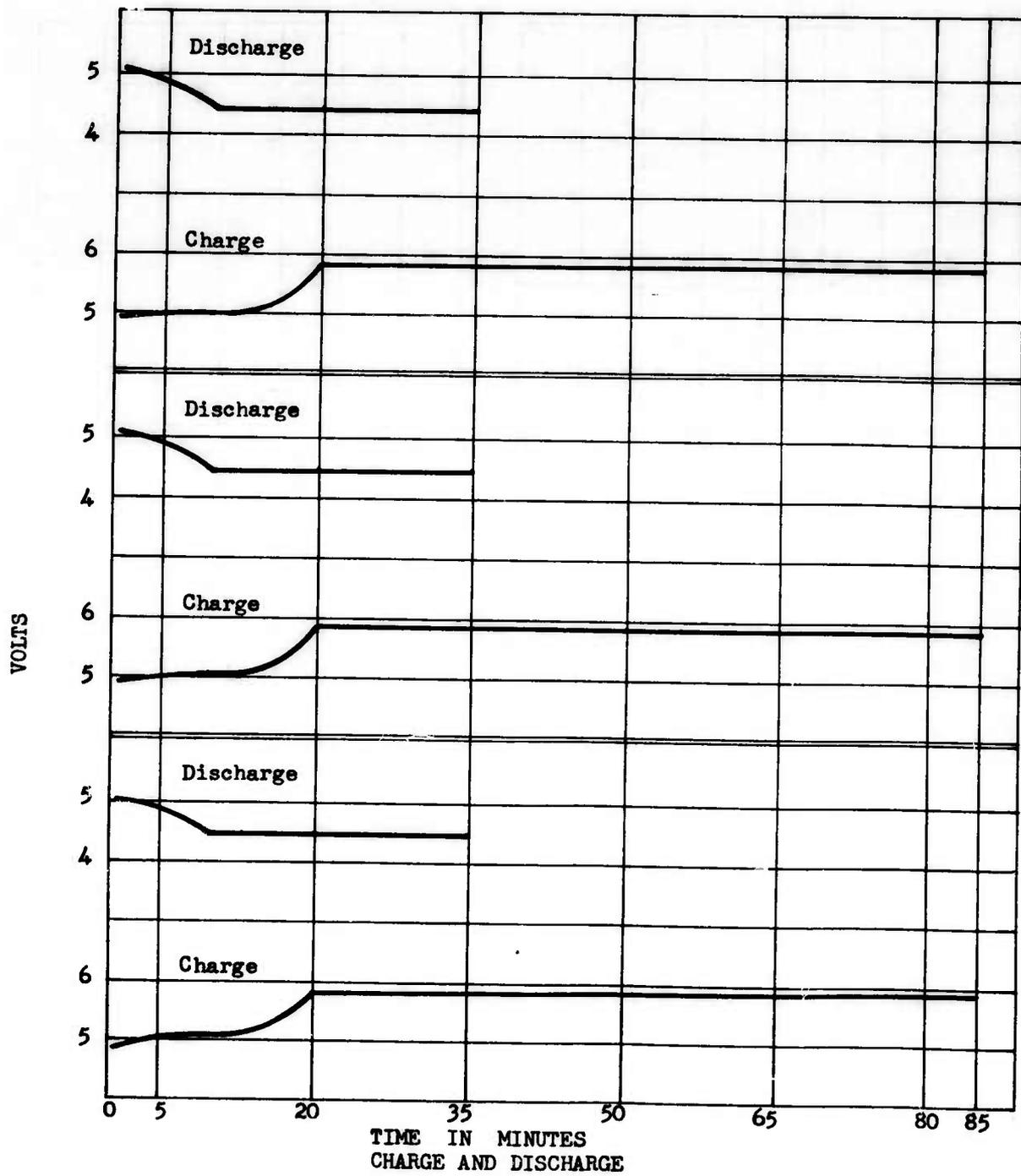
SEALED 3 CELL UNIT VIBRATION - 3 CYCLES

FIGURE 16



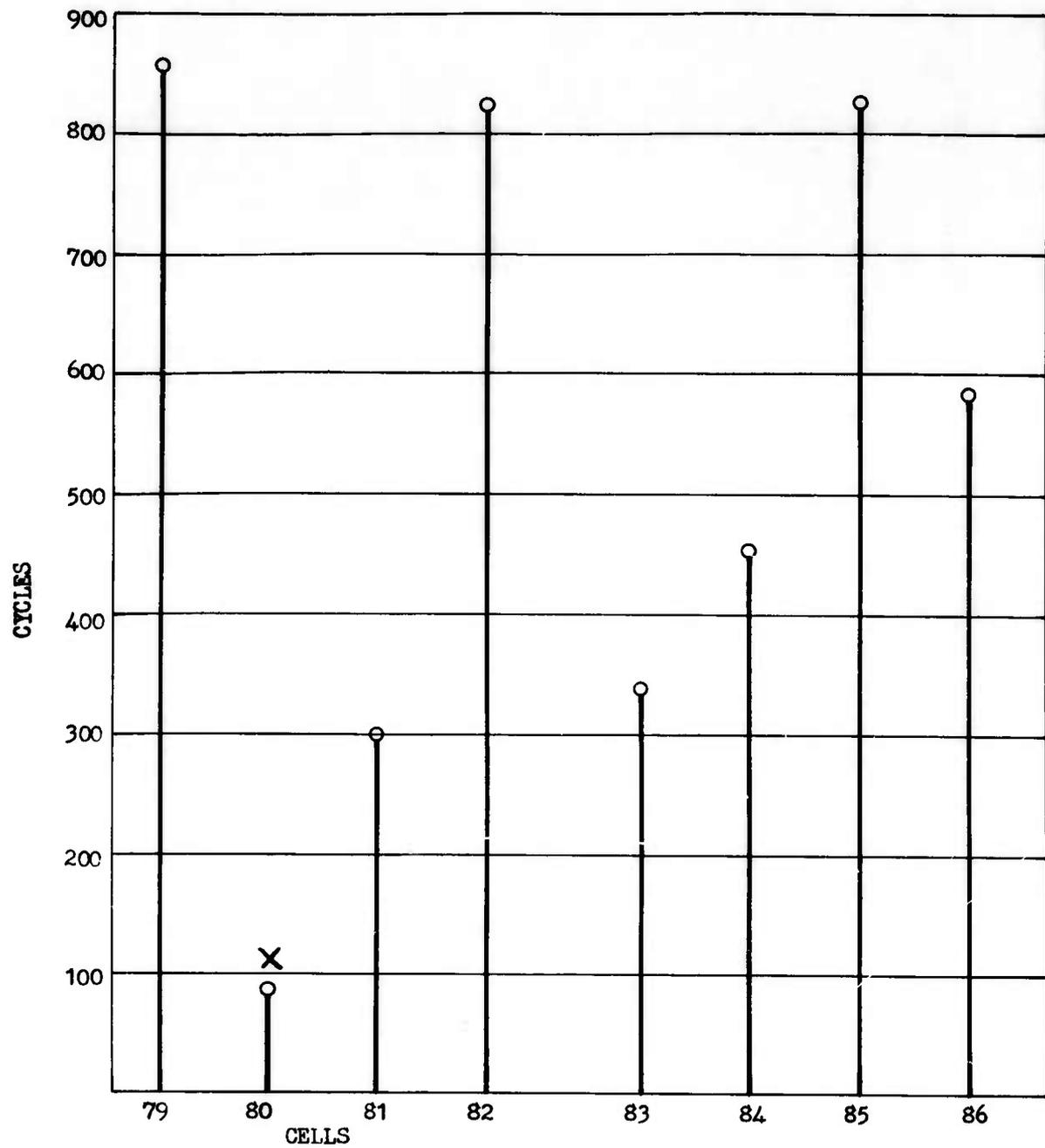
SEALED 3 CELL UNIT

FIGURE 17



SEALED 3 CELL UNIT - PRESSURE TEST 3 CYCLES

FIGURE 18



NUMBER OF CYCLES OBTAINED BY GROUP 5 CELLS DISCHARGED AT 20 AMPERES  
 35 MINUTE DISCHARGE - 85 MINUTE RECHARGE

FIGURE 19

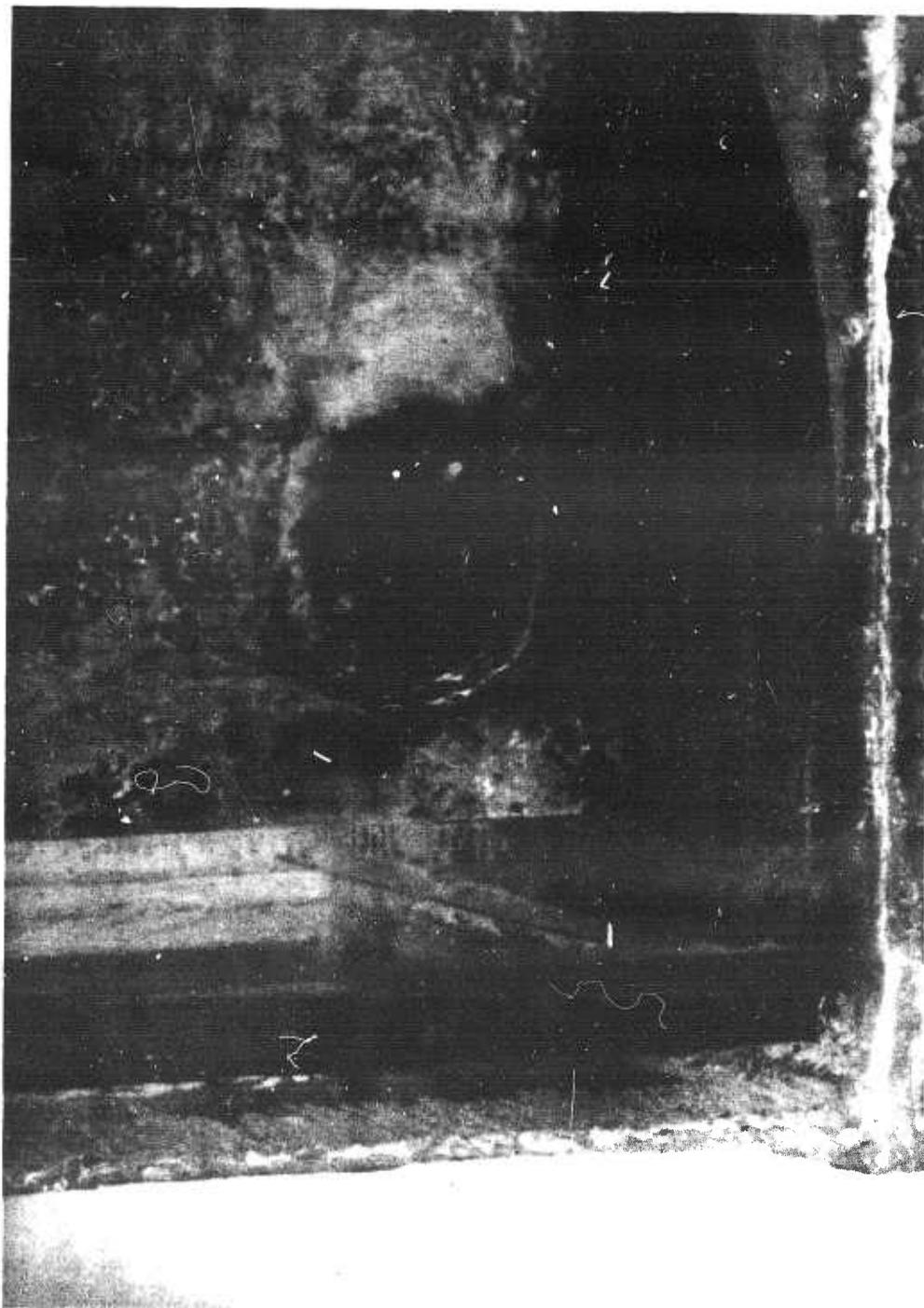


Figure 20. Closeup View of Dendritic Zinc Short

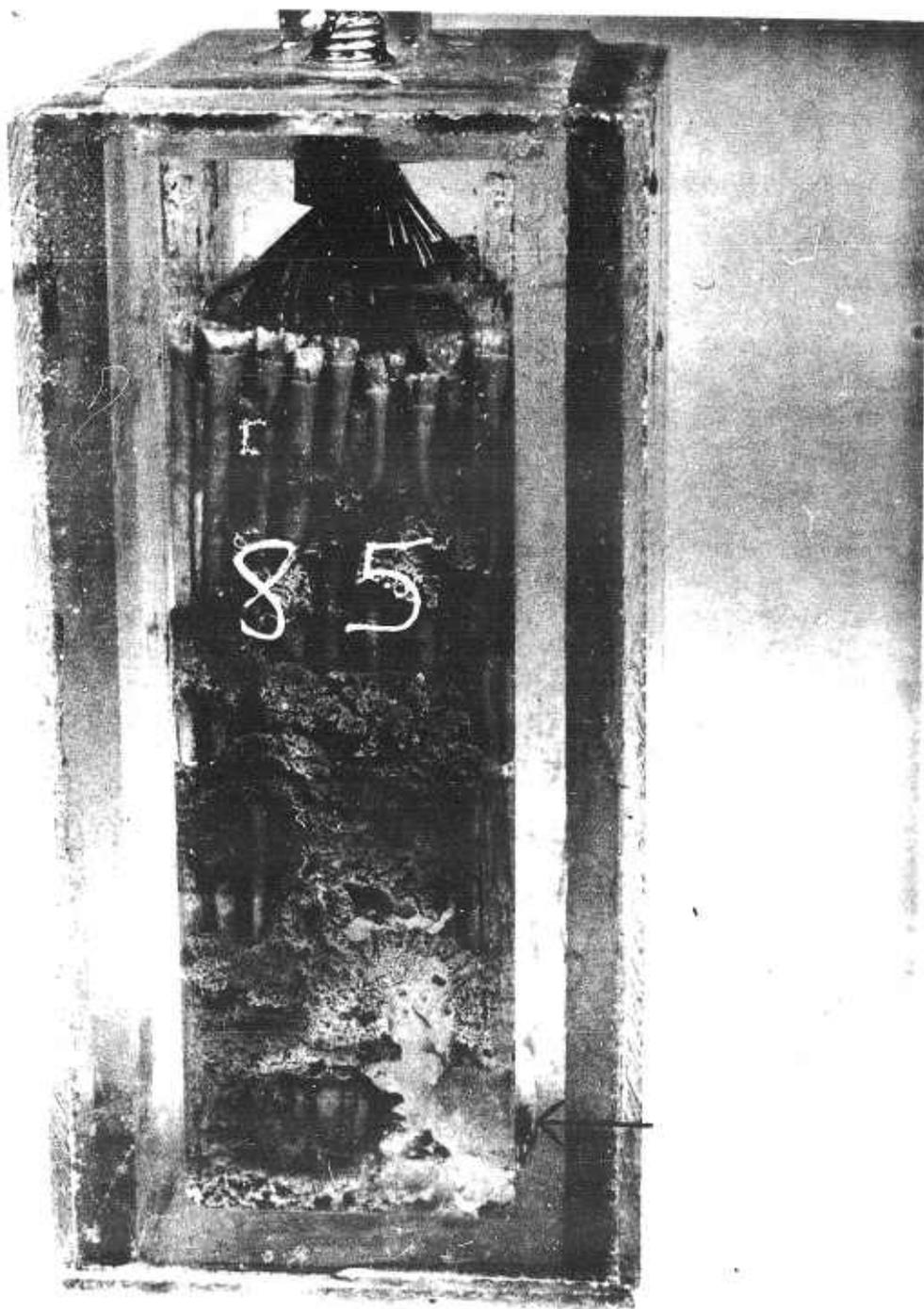


Figure 21. Zinc Treeing in Cell

APPENDIX III

SUPPORTING DATA FOR PART III

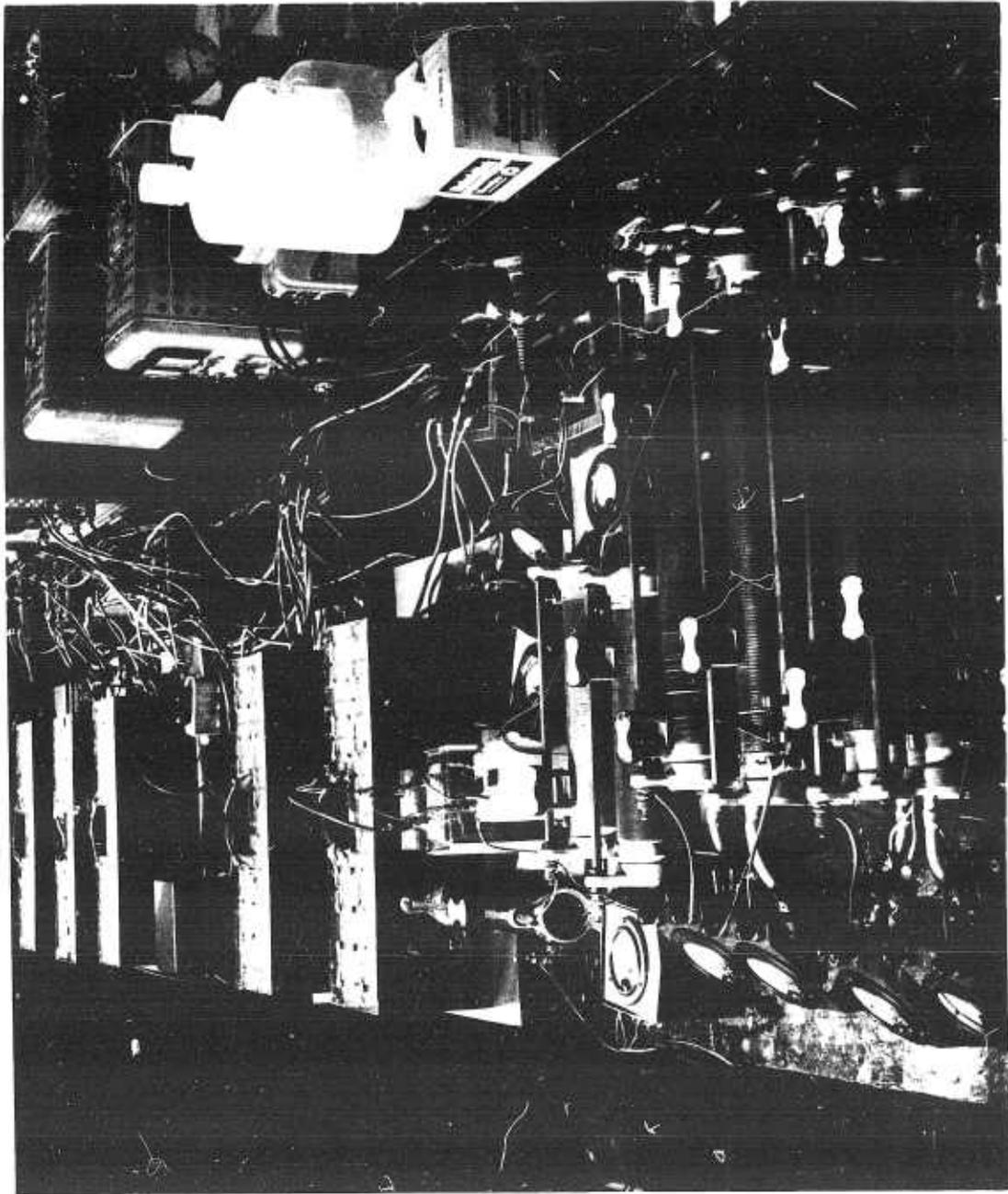
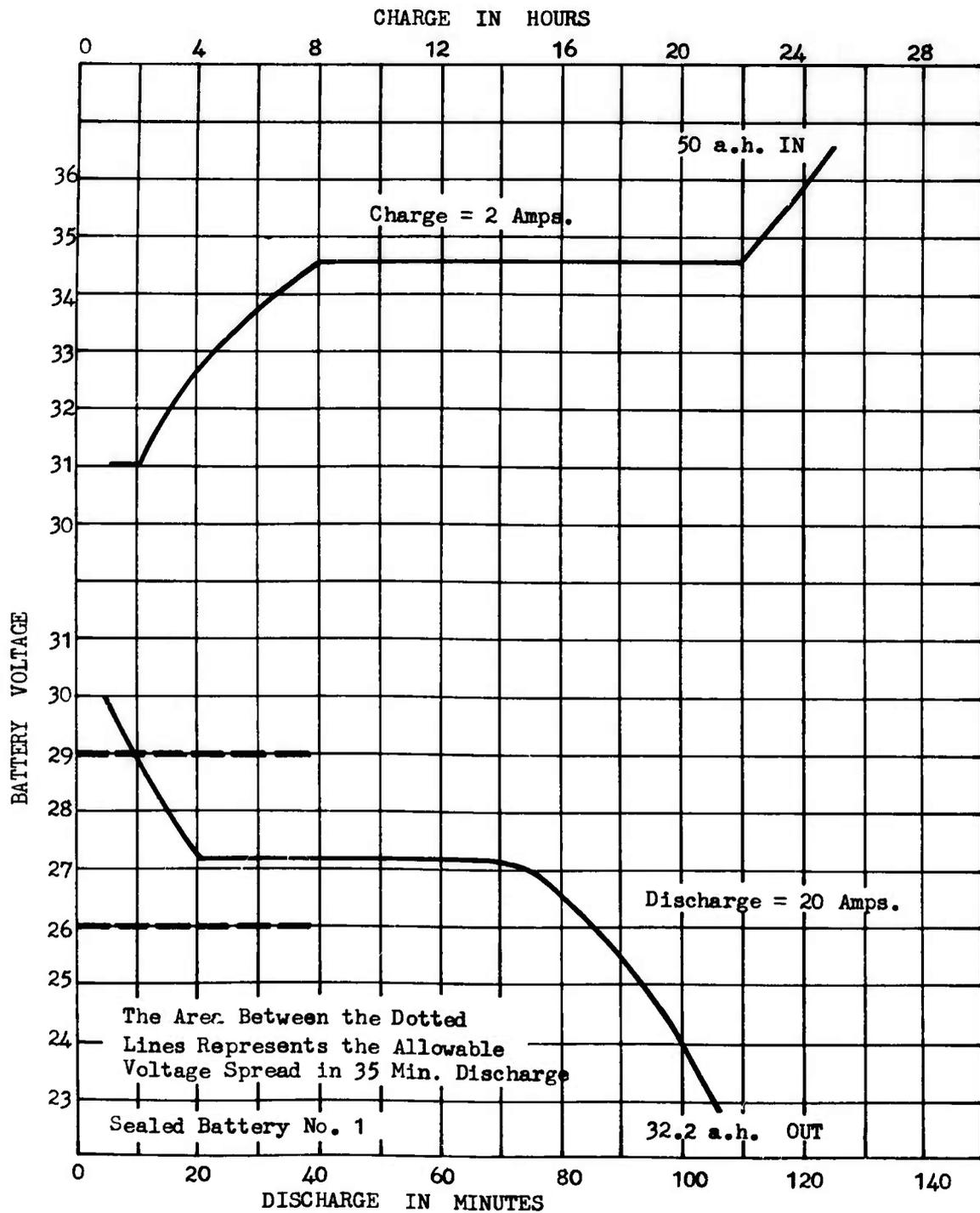
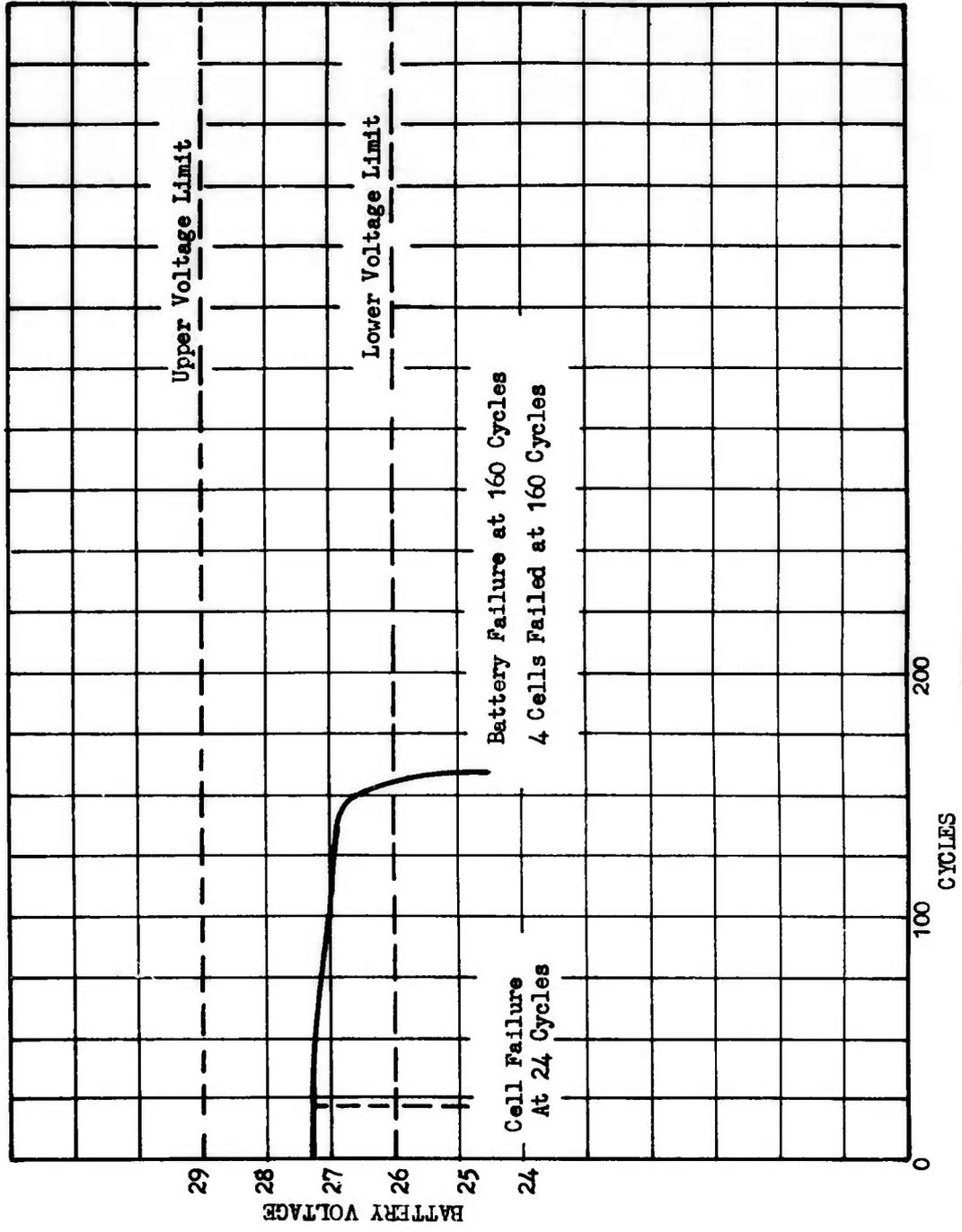


Figure 22. Sealed Batteries on Cycle Life Test



INITIAL CHARGE AND DISCHARGE

FIGURE 23



BATTERY No. 1

END OF DISCHARGE VOLTAGES

FIGURE 24

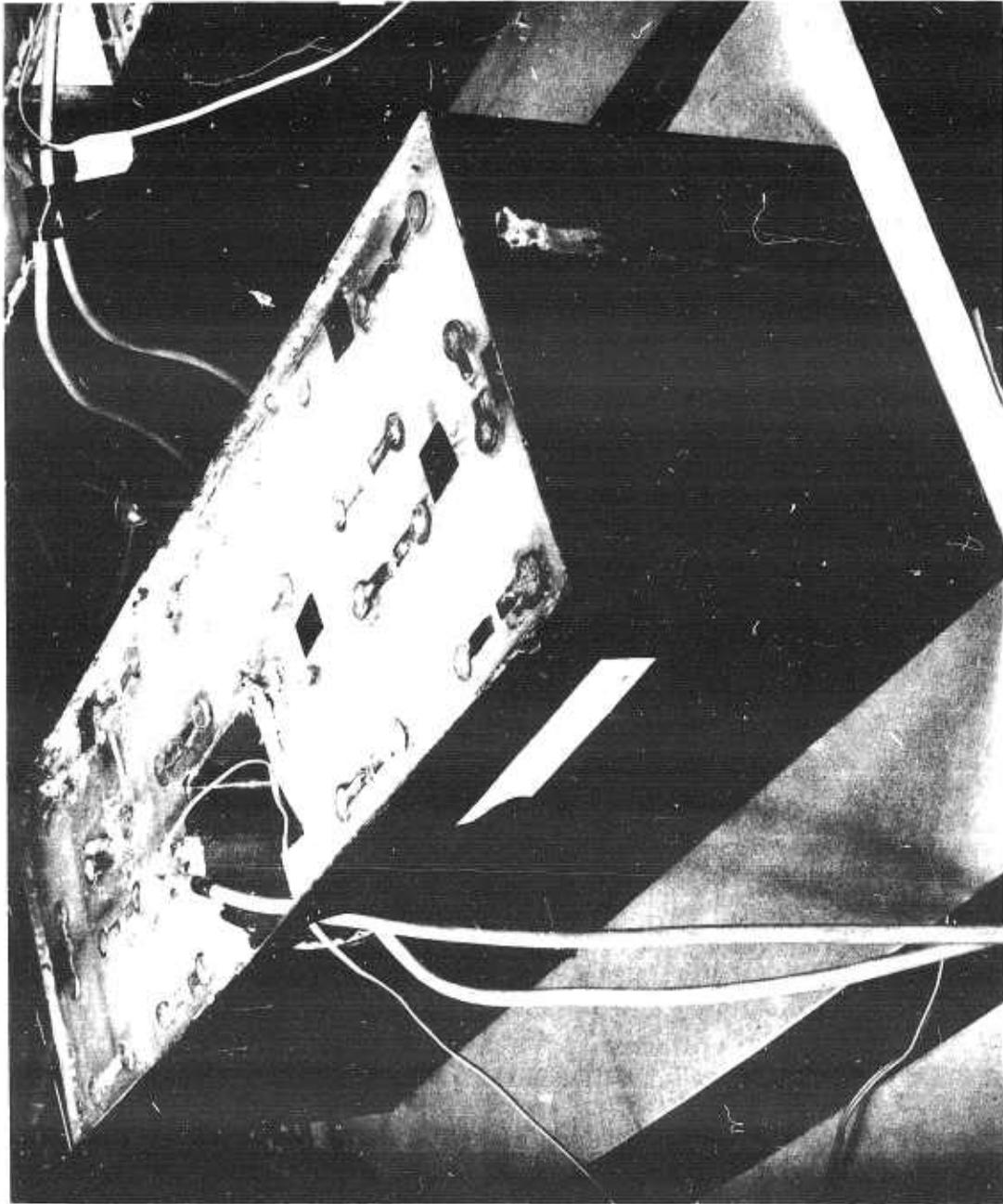


Figure 25. Battery #1 After Failure at 160 Cycles

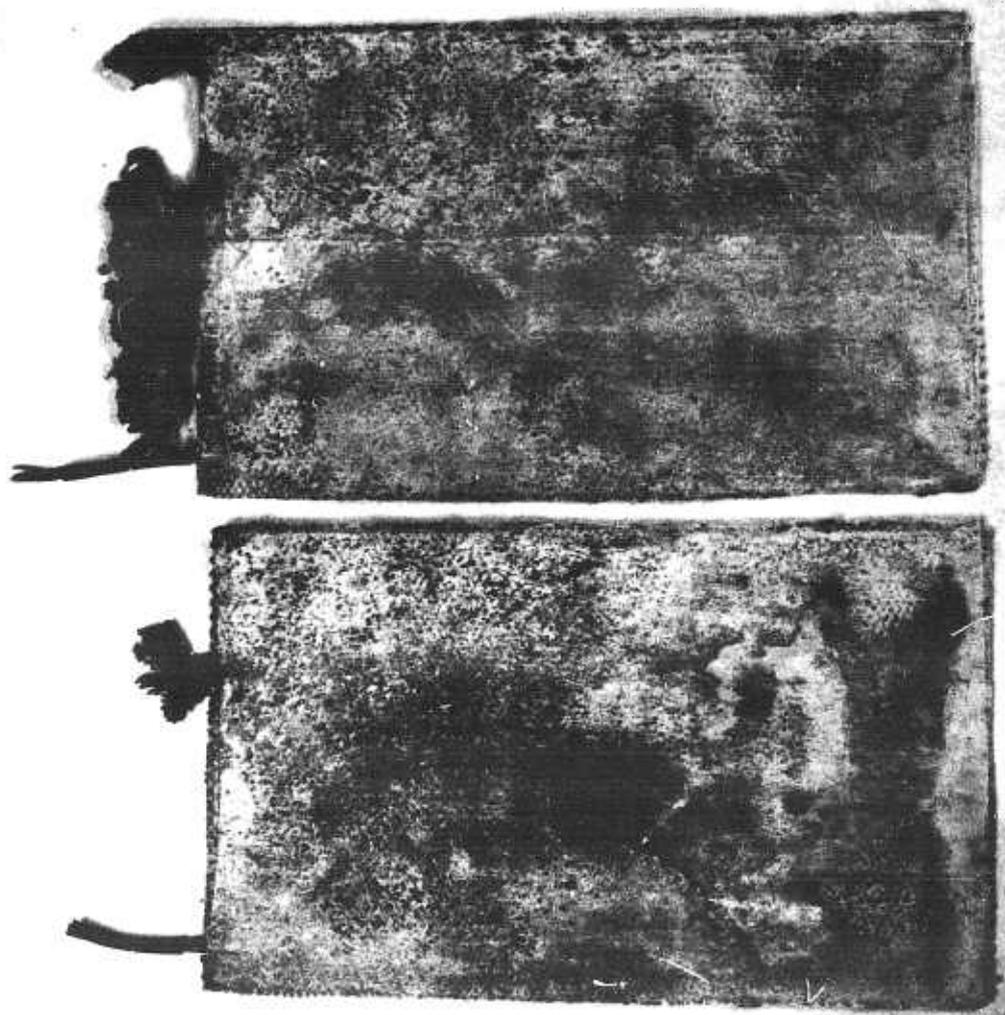


Figure 26. Typical Zinc Negative Plate Treeing

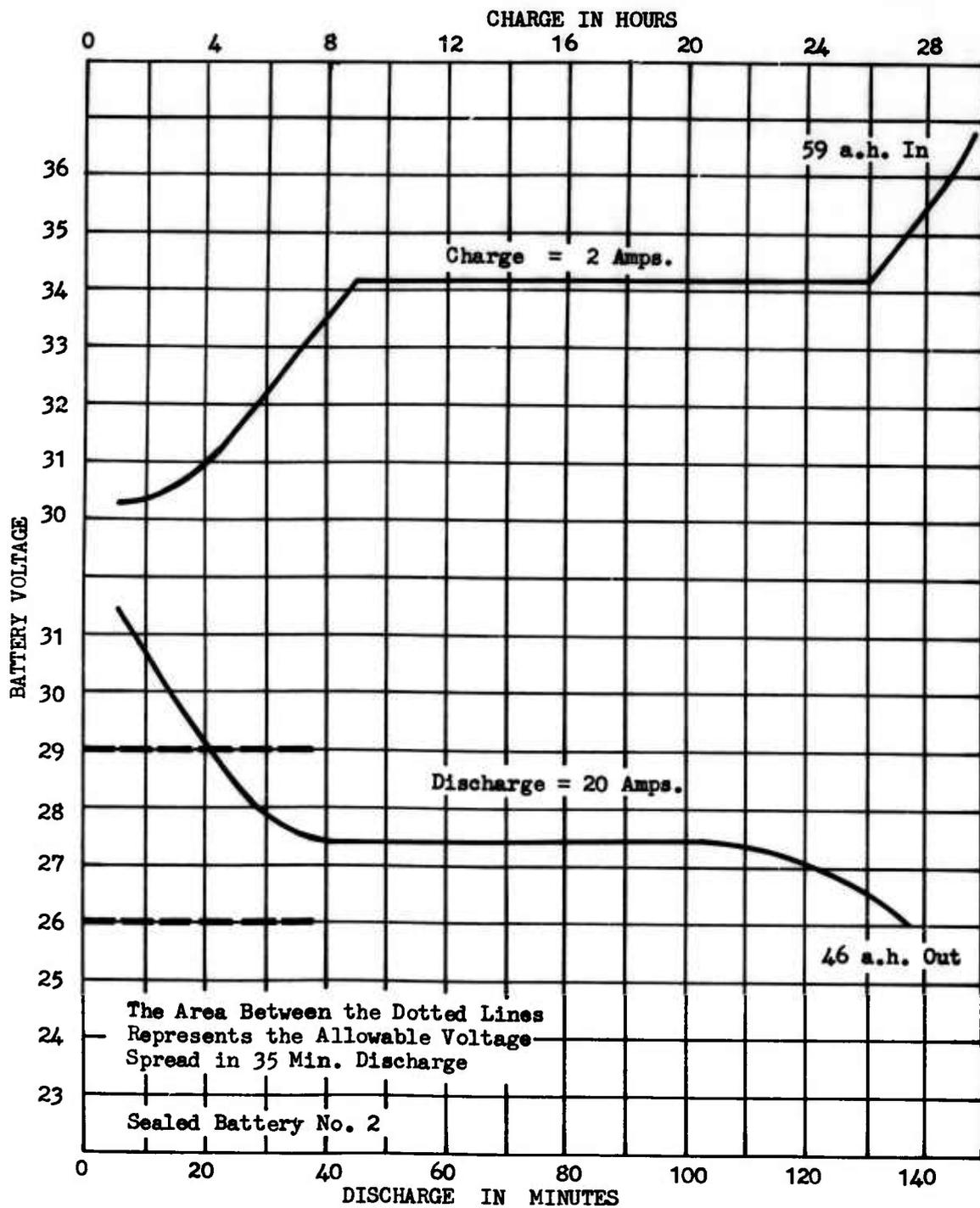
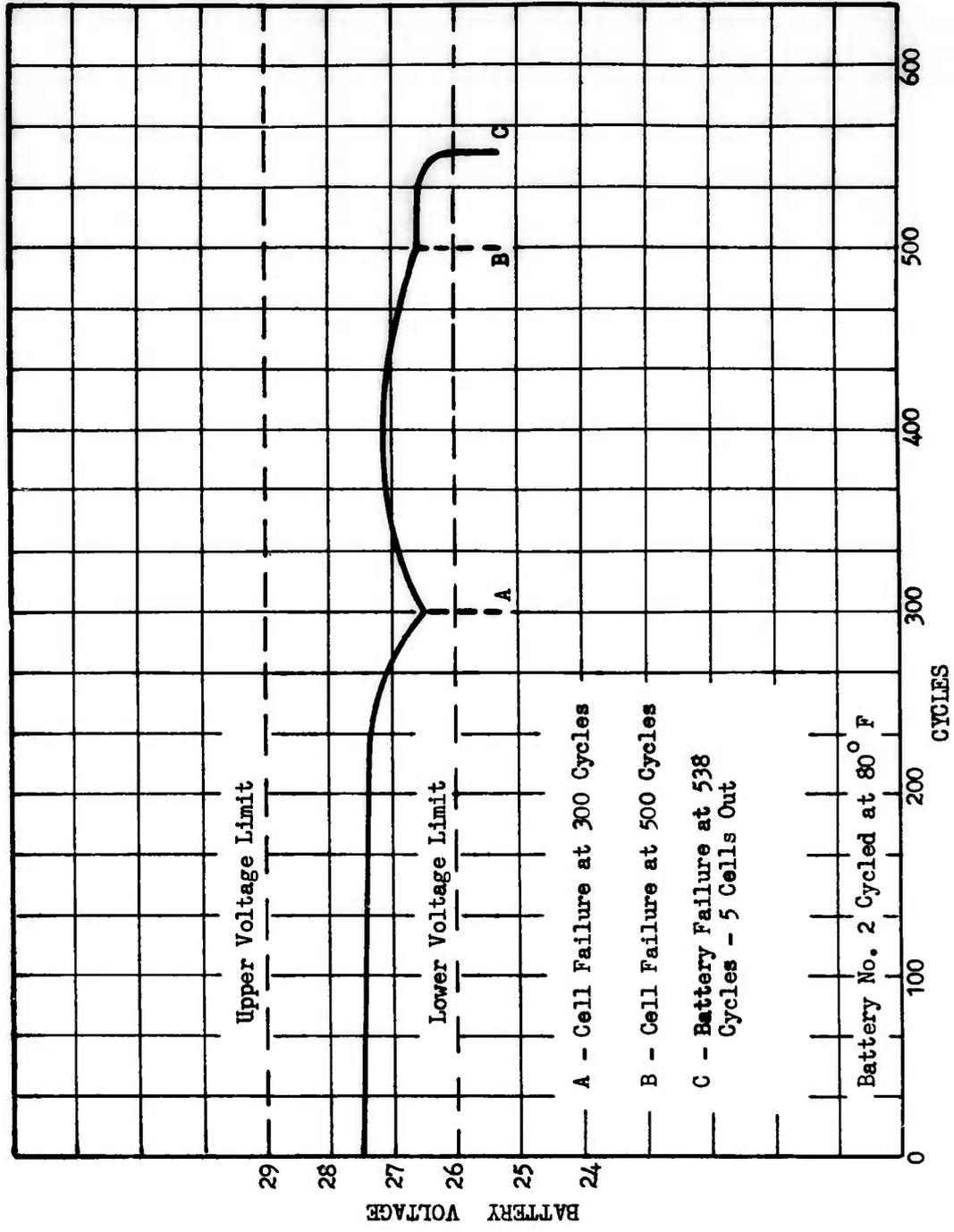


FIGURE 27



END OF DISCHARGE VOLTAGE

FIGURE 28

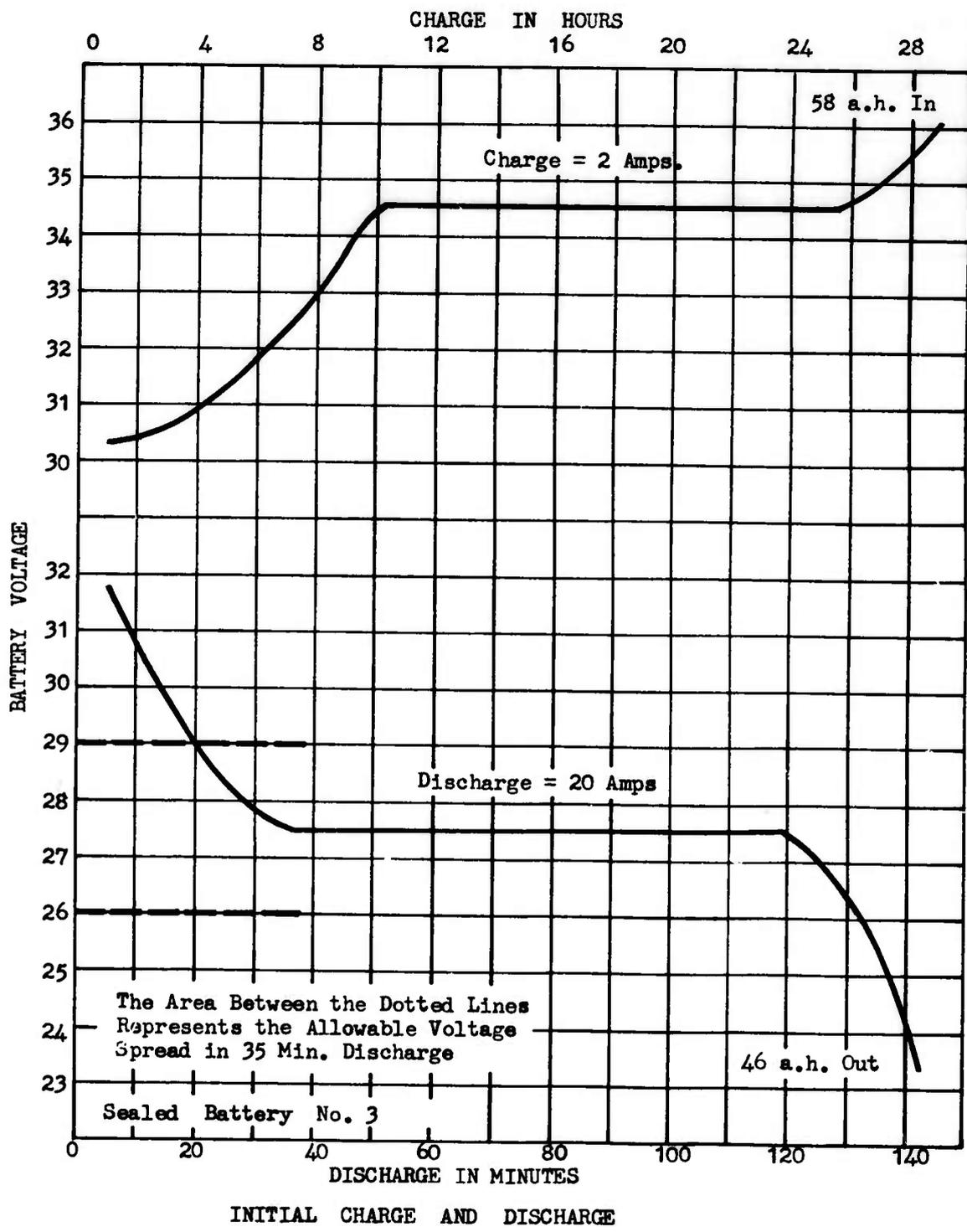
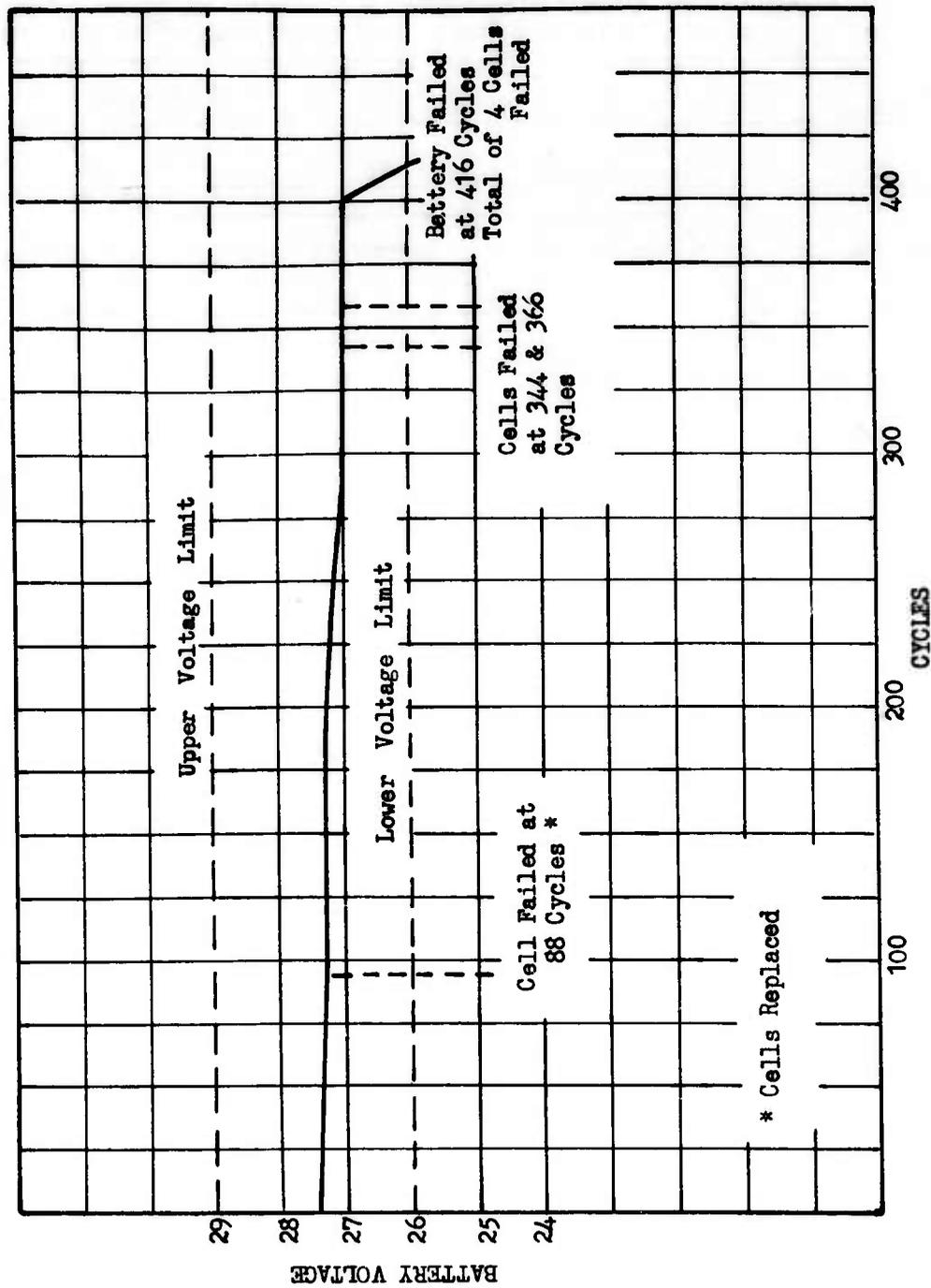


FIGURE 29



BATTERY No. 3

END OF DISCHARGE VOLTAGE

FIGURE 30

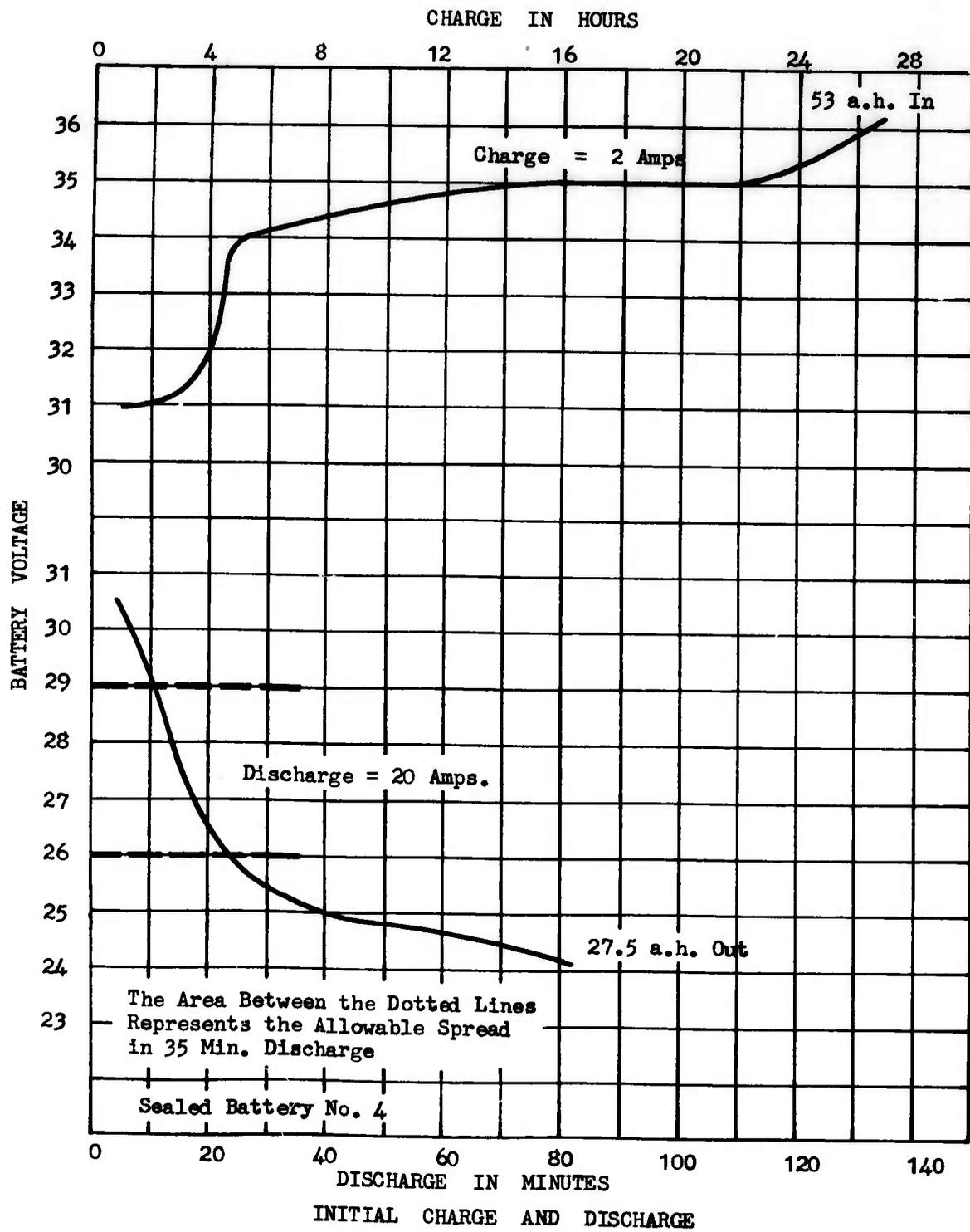
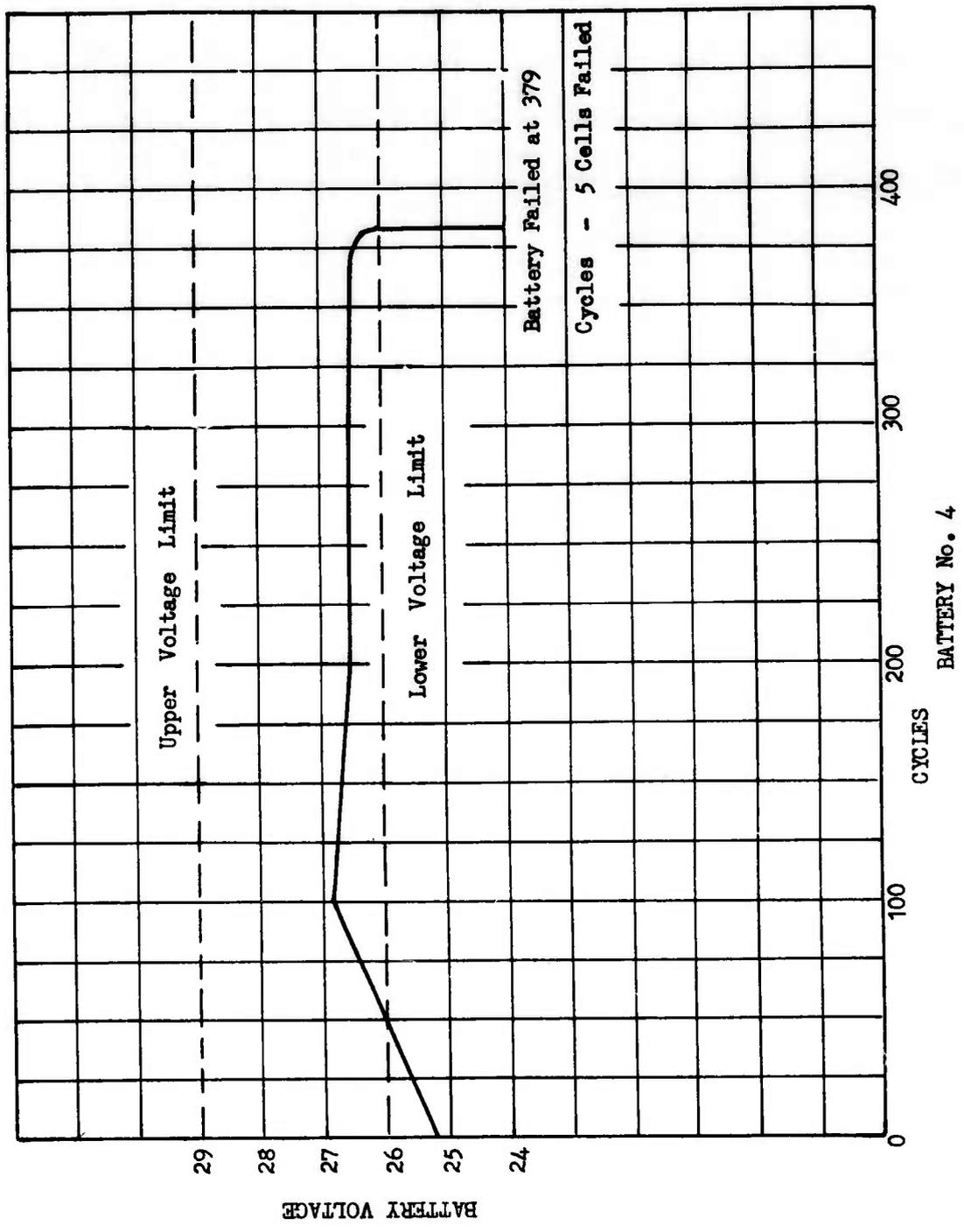


FIGURE 31



BATTERY No. 4  
END OF DISCHARGE VOLTAGE

FIGURE 32

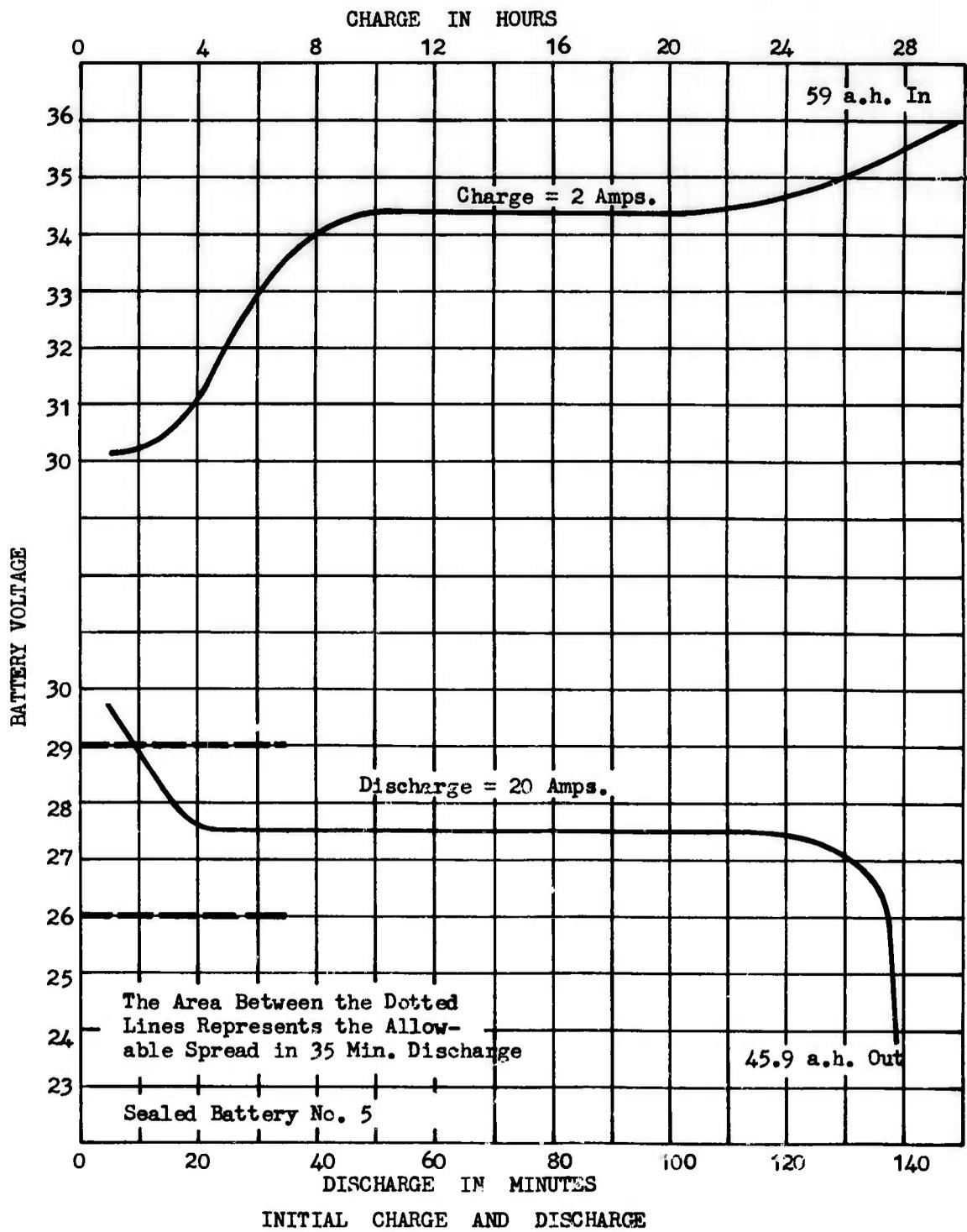
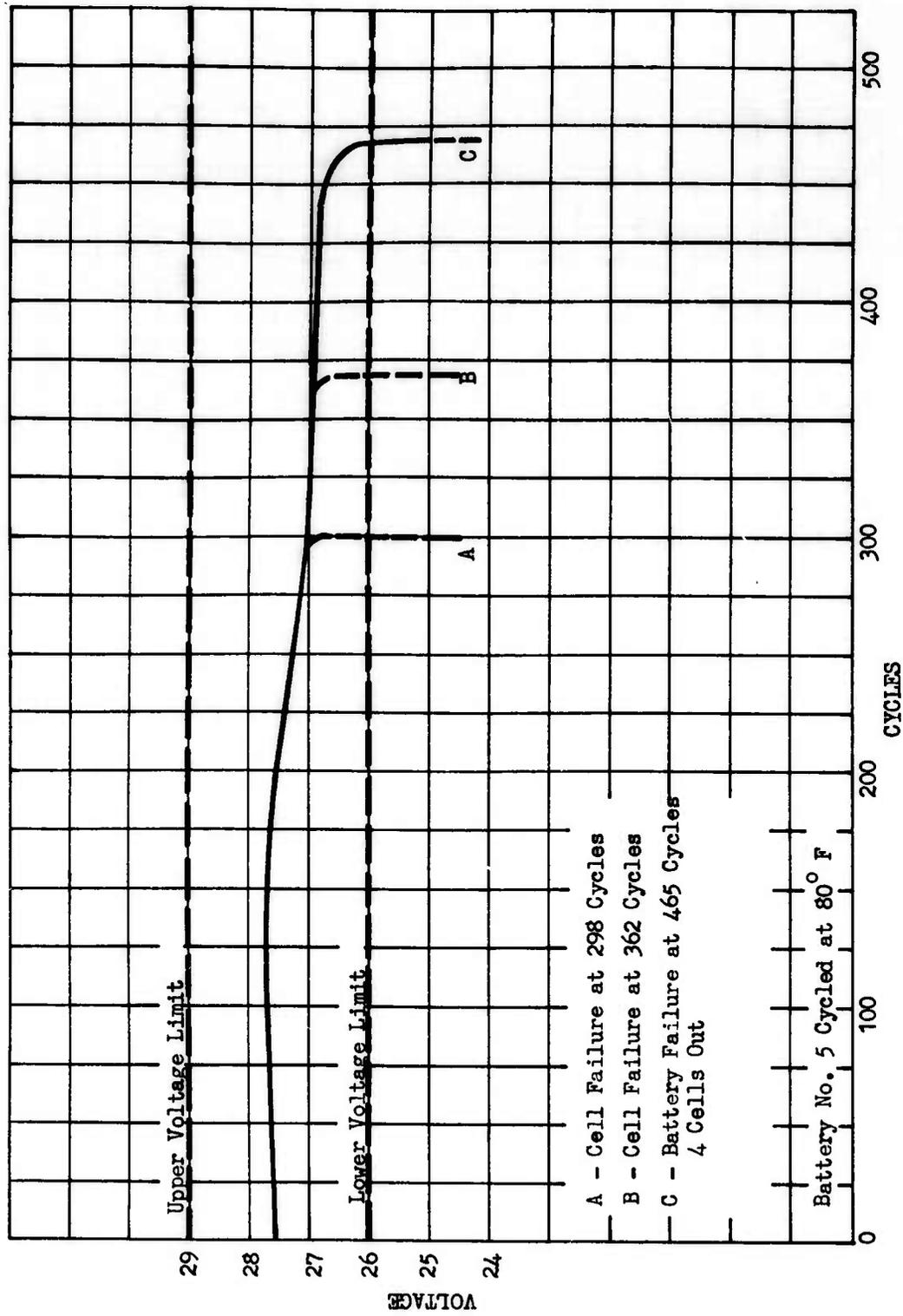
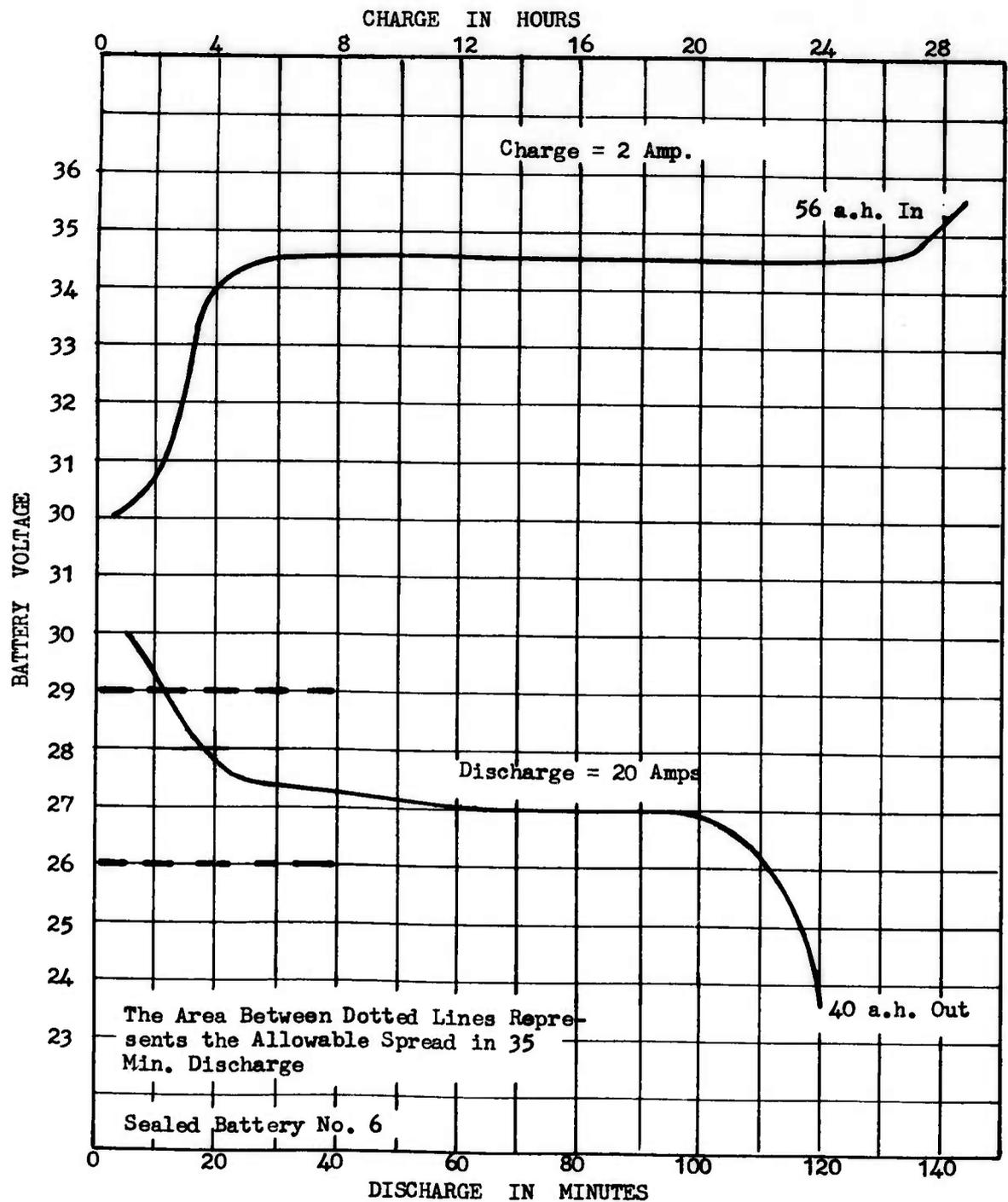


FIGURE 53



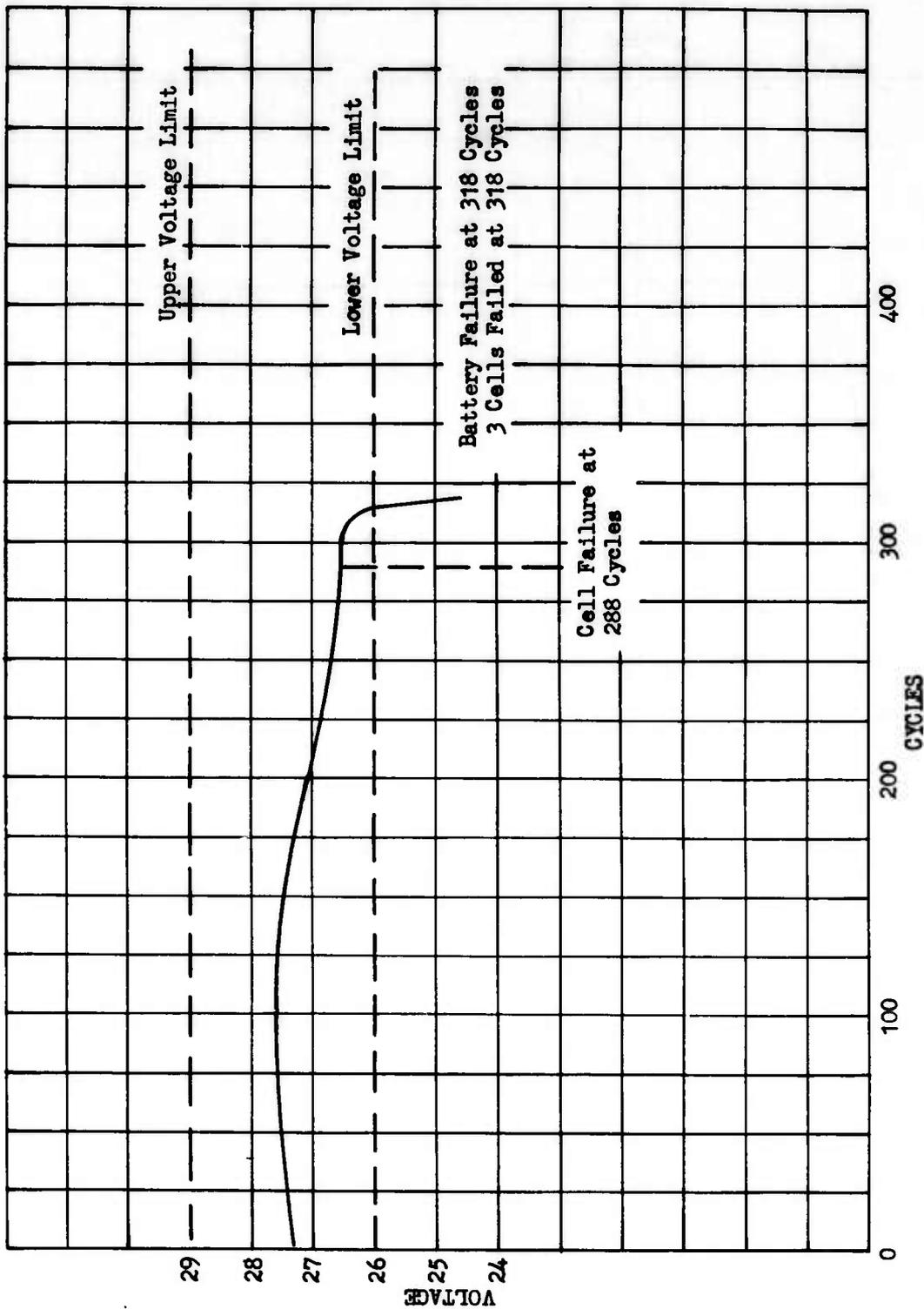
END OF DISCHARGE VOLTAGE

FIGURE 34

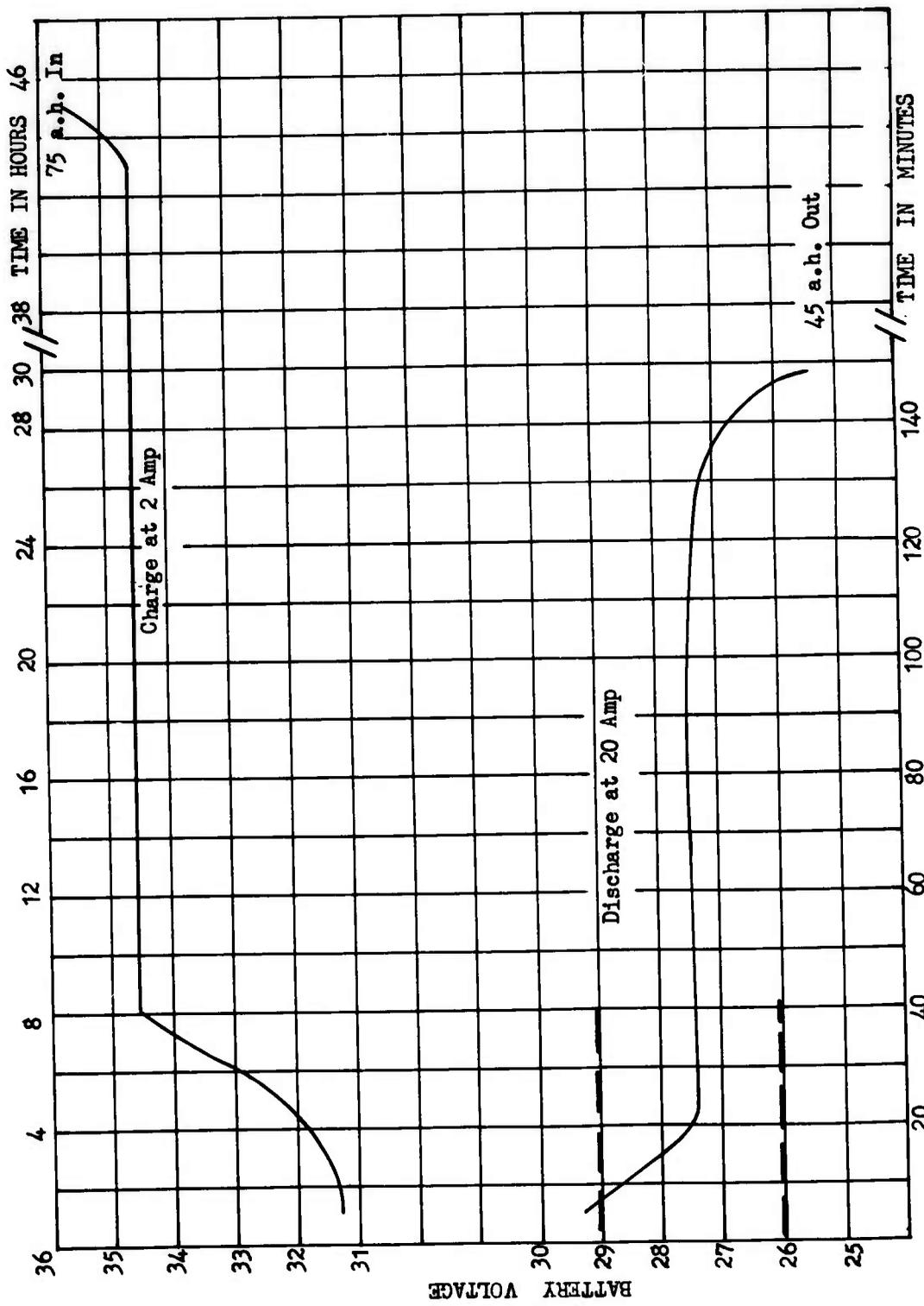


INITIAL CHARGE AND DISCHARGE

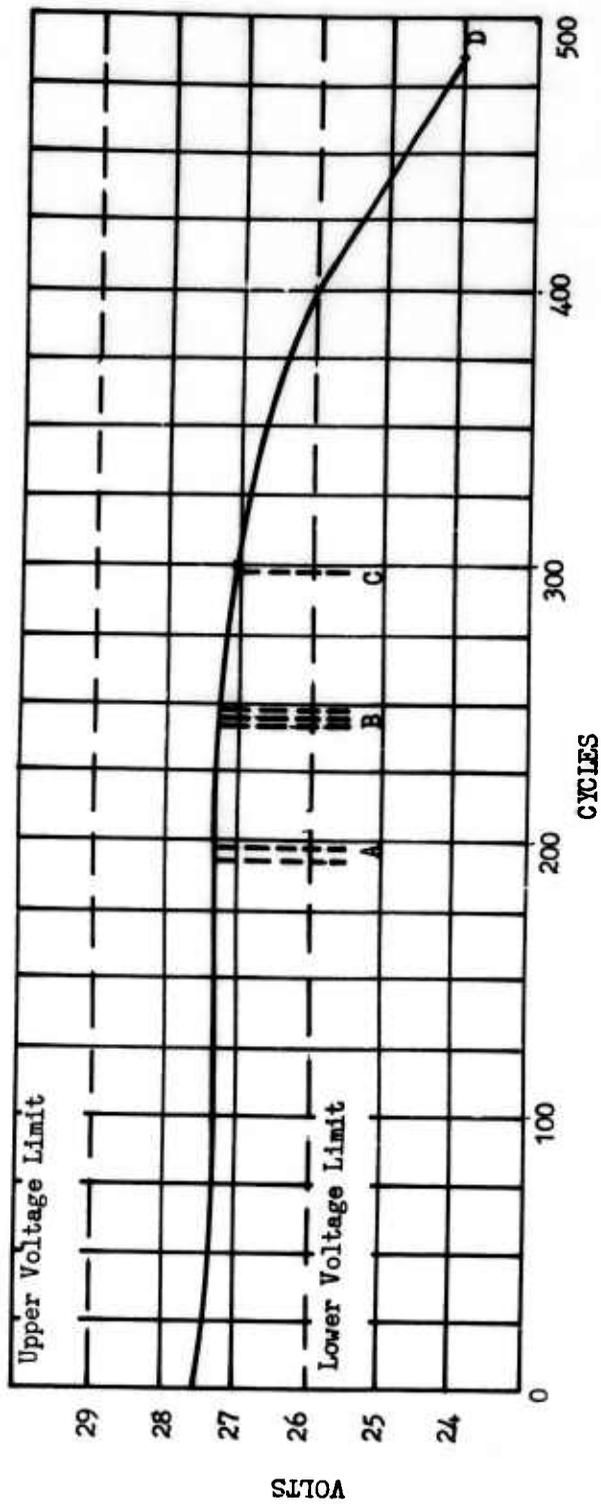
FIGURE 35



BATTERY No. 6  
 END OF DISCHARGE VOLTAGES  
 FIGURE 36



SEALED BATTERY No. 7  
 INITIAL CHARGE AND DISCHARGE  
 FIGURE 37

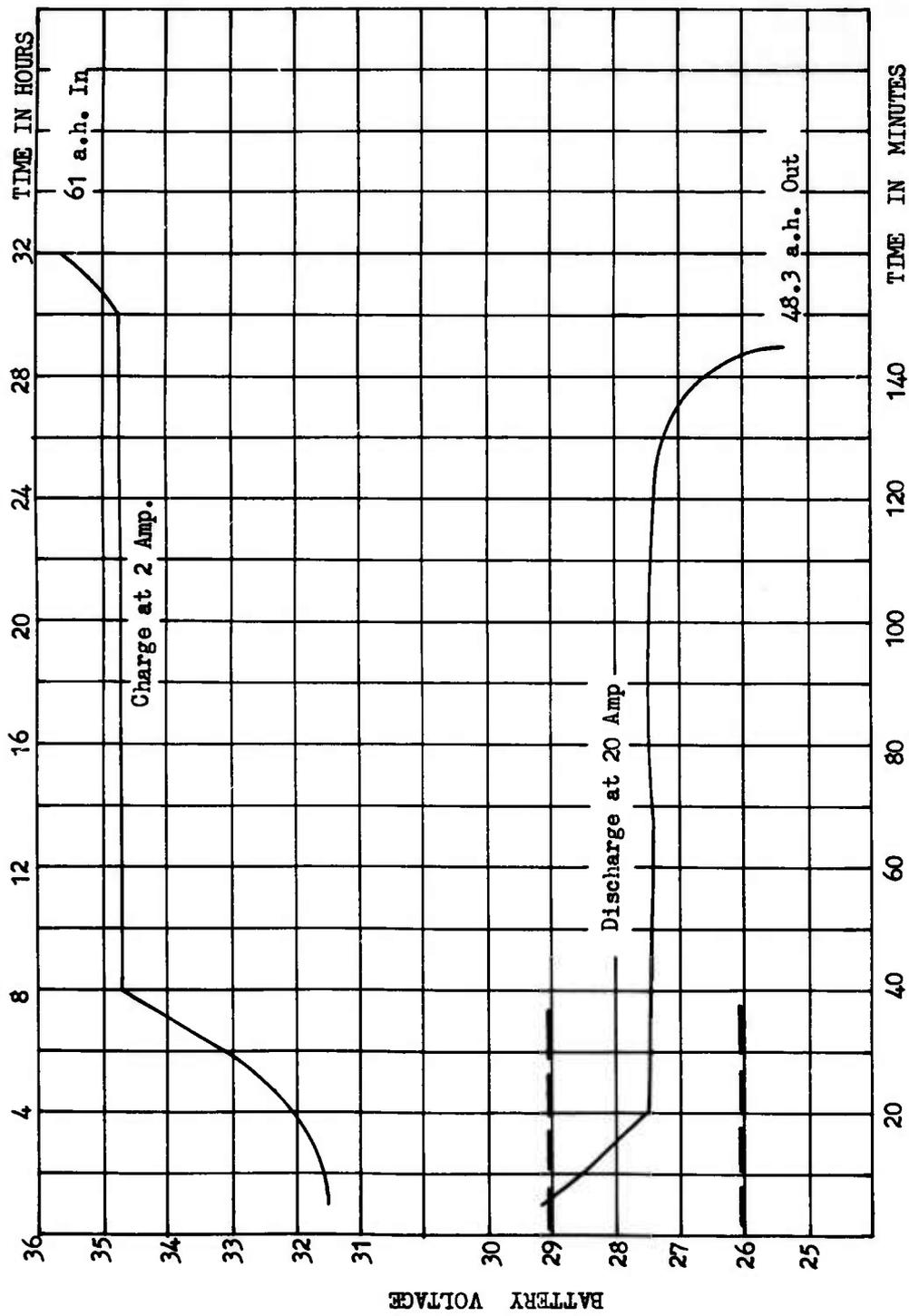


- A = Cells failed at 188 and 199 cycles
- B = Cells failed at 244 cycles = Battery failure at 244 Cycles
- C = Cell failed at 299 cycles
- D = Total of 9 cells out at 489 cycles.

Battery No. 7 Cycles at 80° F.

END OF DISCHARGE VOLTAGES

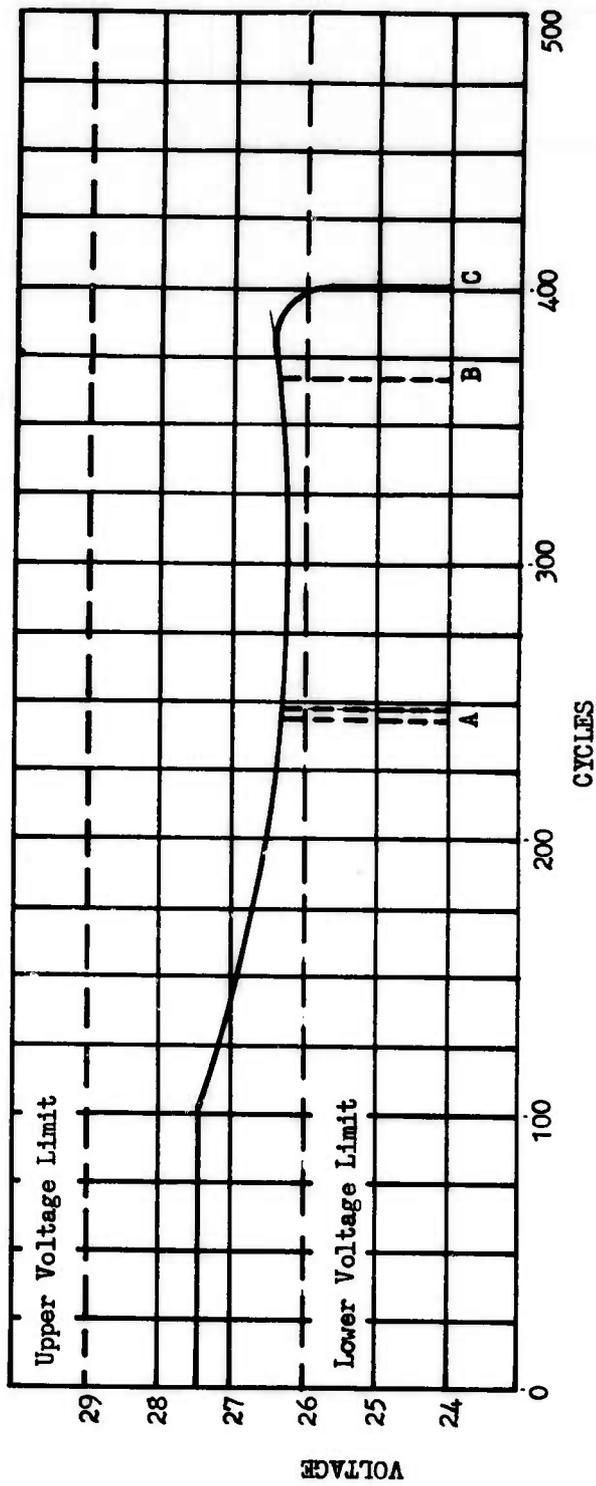
FIGURE 38



BATTERY No. 8

INITIAL CHARGE AND DISCHARGE

FIGURE 39



A = 2 cells failed at 247 cycles

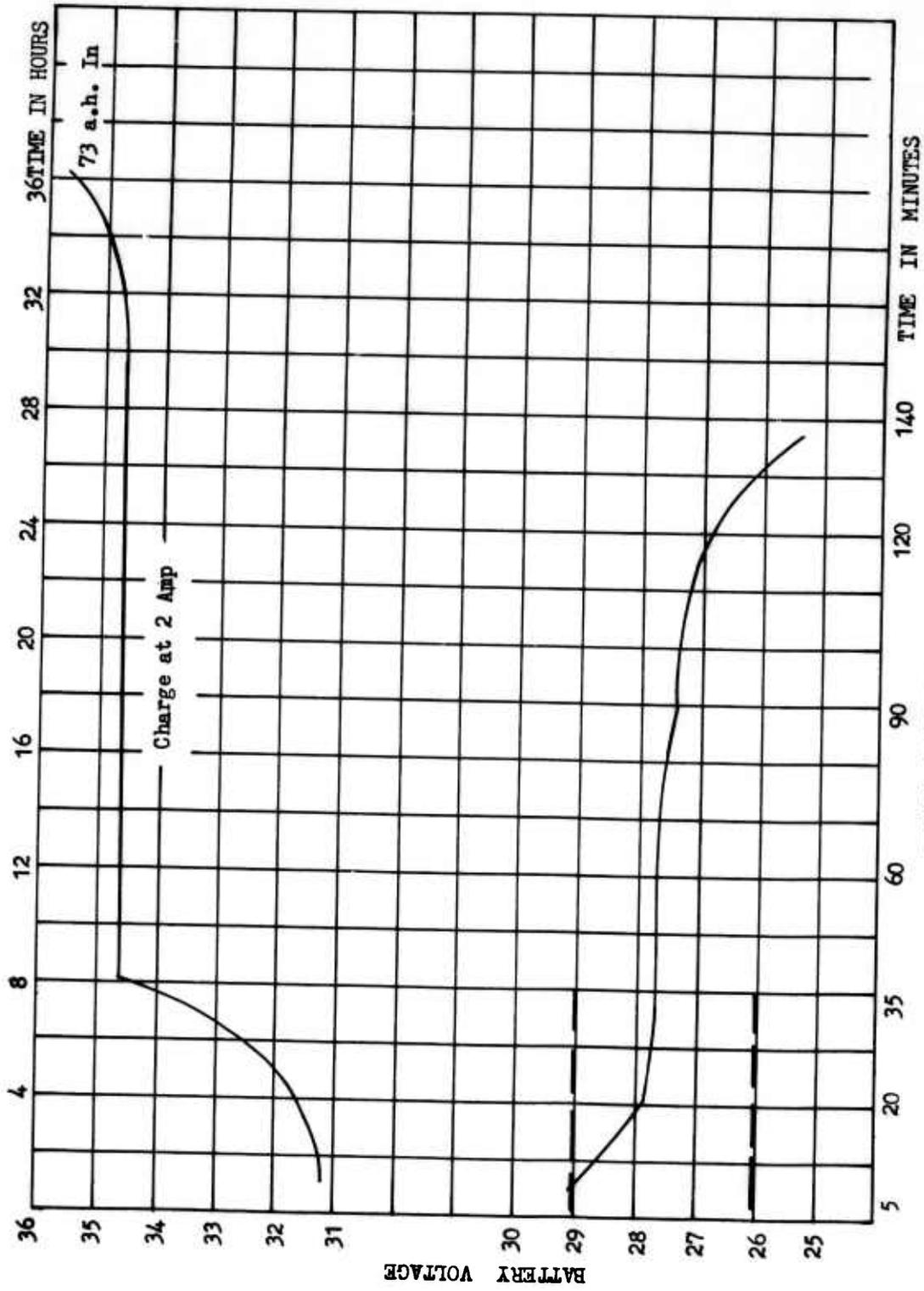
B = Cell failed at 364 cycles = Battery failed at 364 Cycles

C = 10 cells failed at 400 cycles

Battery No. 8 Cycled at 100° F.

END OF DISCHARGE VOLTAGES

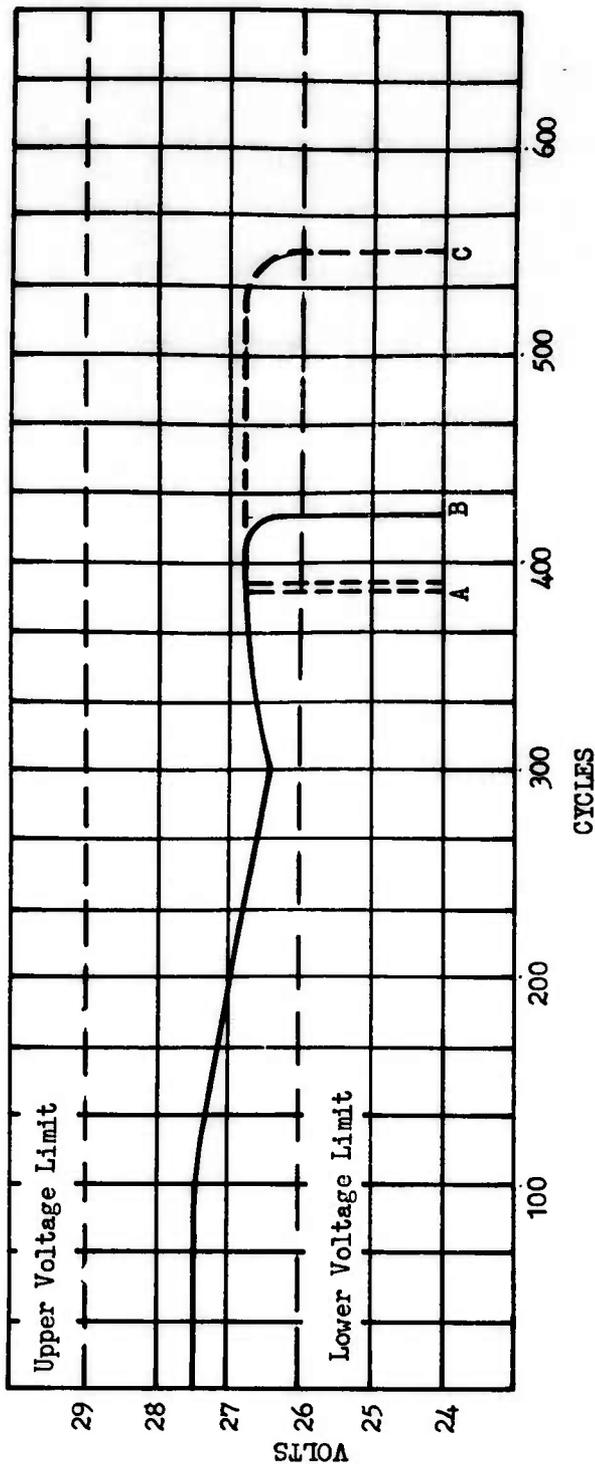
FIGURE 40



SEALED BATTERY No. 9

INITIAL CHARGE AND DISCHARGE

FIGURE 41



A - 2 cells failed at 388 cycles.

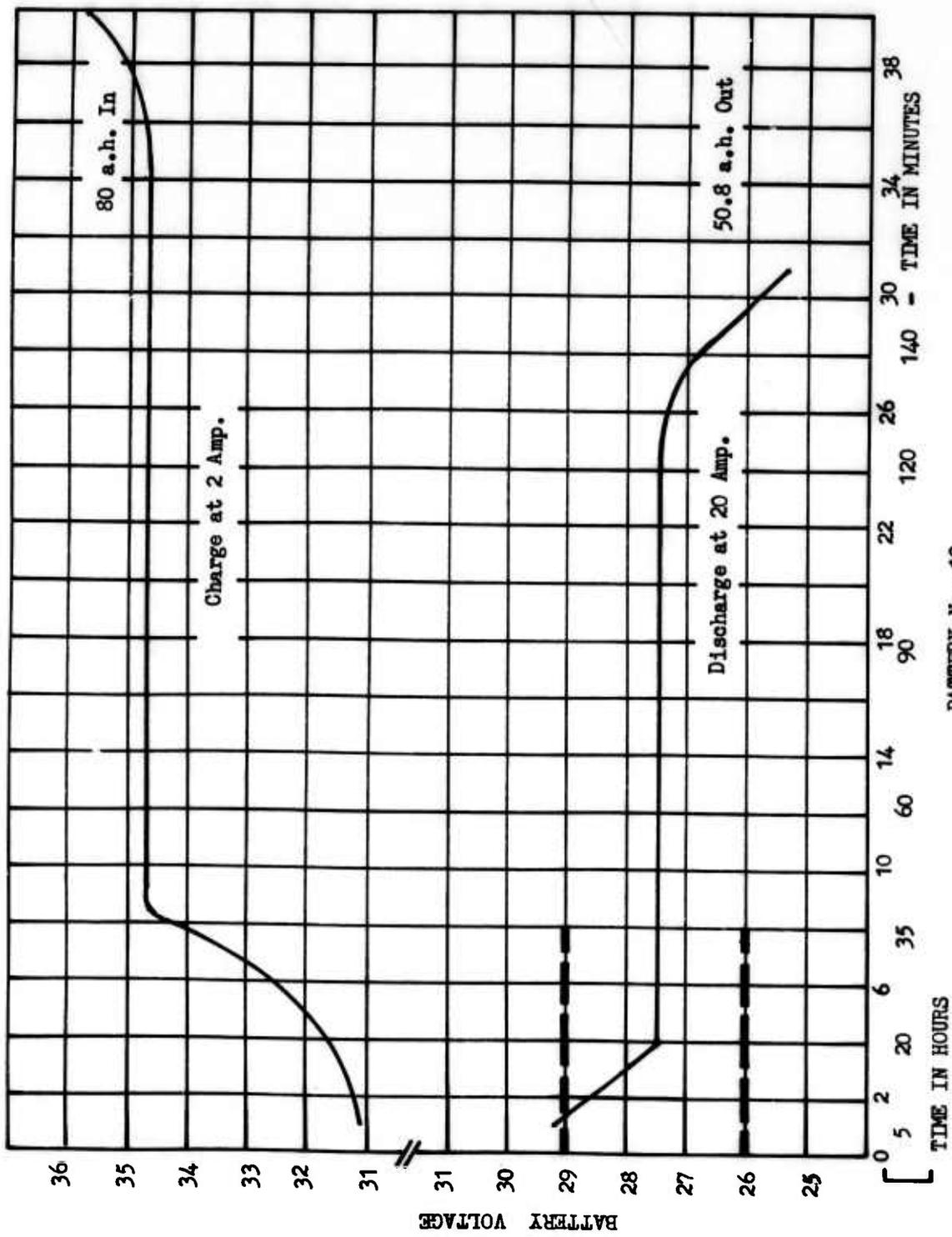
B - Battery failed at 421 cycles - 3 cells out

C - 9 cells failed at 552 cycles - Battery off

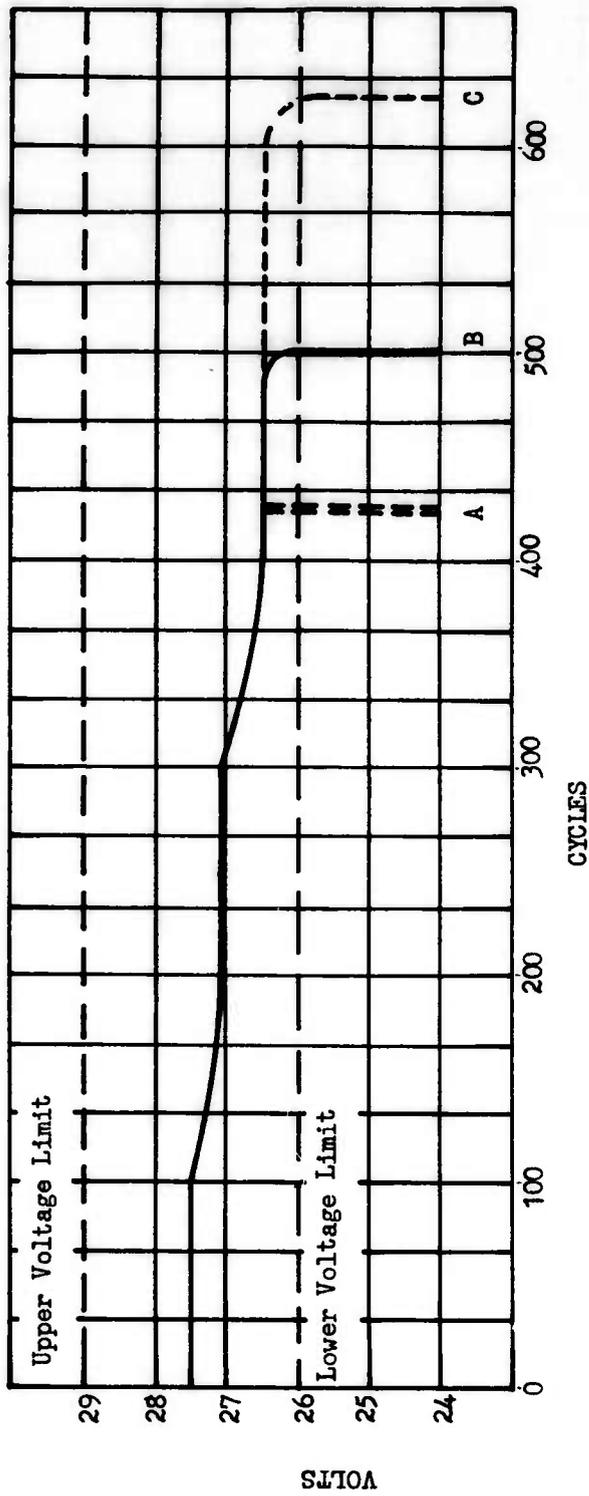
Battery No. 9 Cycled at 50° F.

END OF DISCHARGE VOLTAGES

FIGURE 42



BATTERY No. 10  
 INITIAL CHARGE AND DISCHARGE  
 FIGURE 43



A - 2 cells failed at 421 cycles

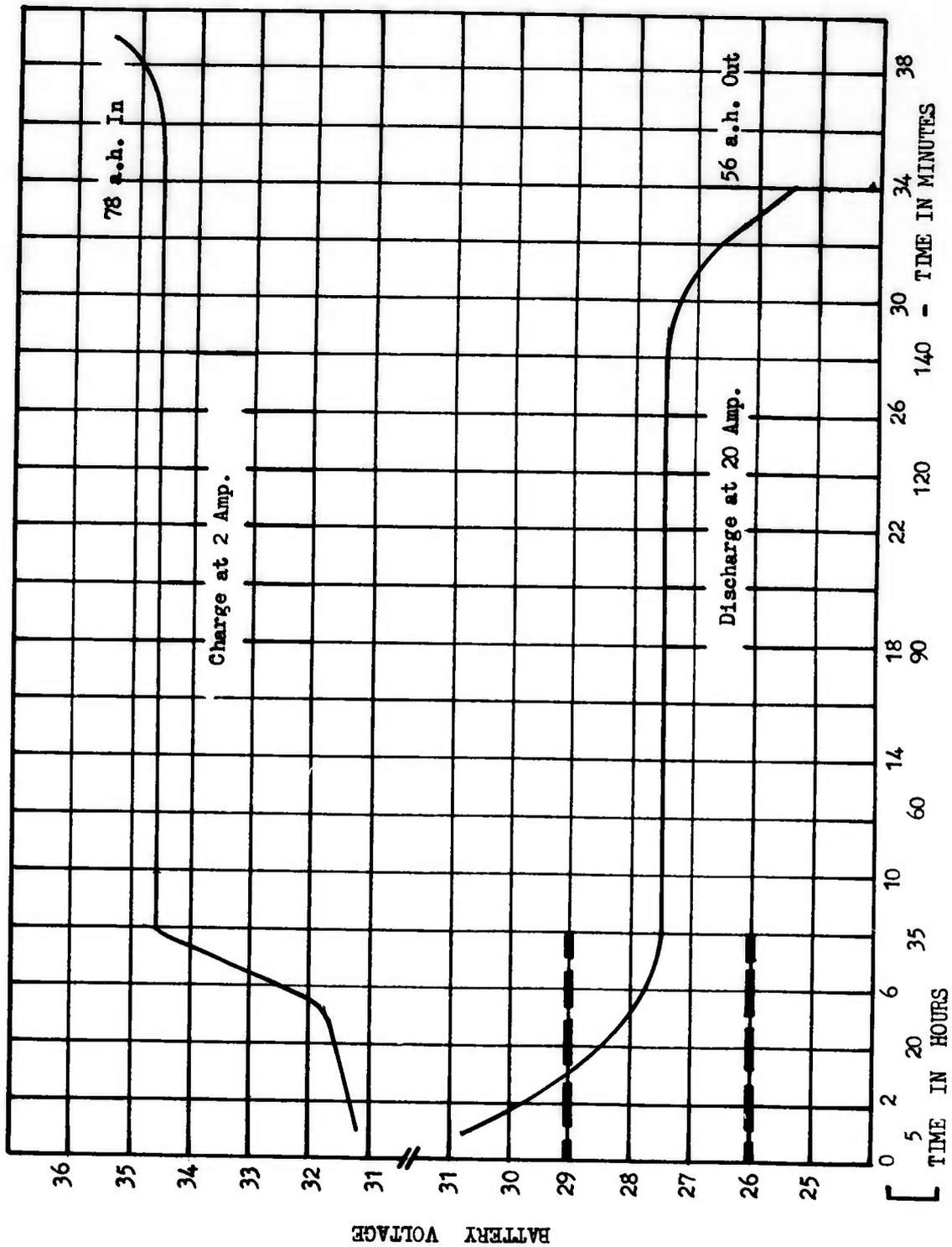
B - 1 cell failed at 500 cycles - Battery failed

C - 9 cells out - Battery off - 620 cycles

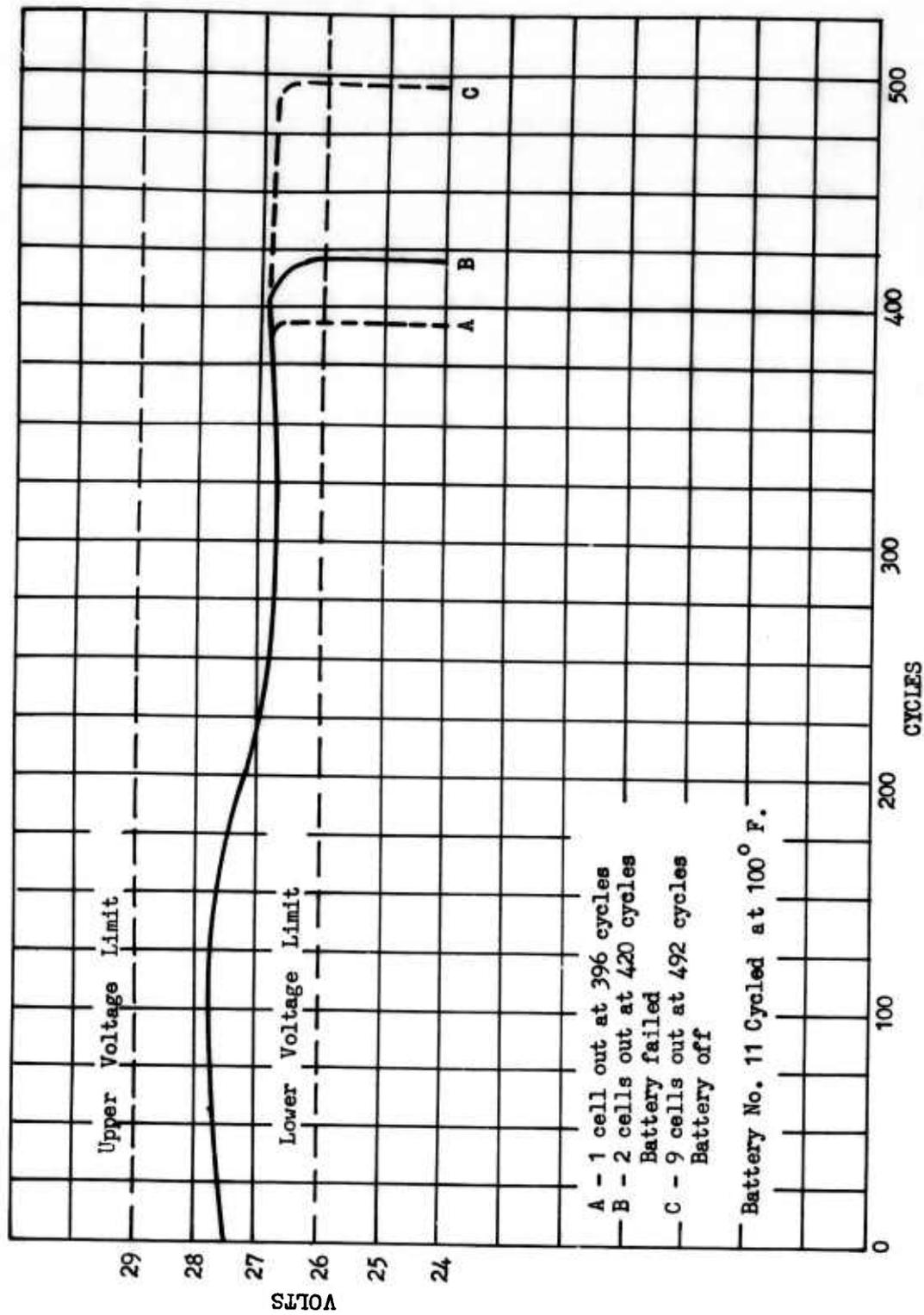
Battery No. 10 Cycled at 50°F

END OF DISCHARGE VOLTAGES

FIGURE 44

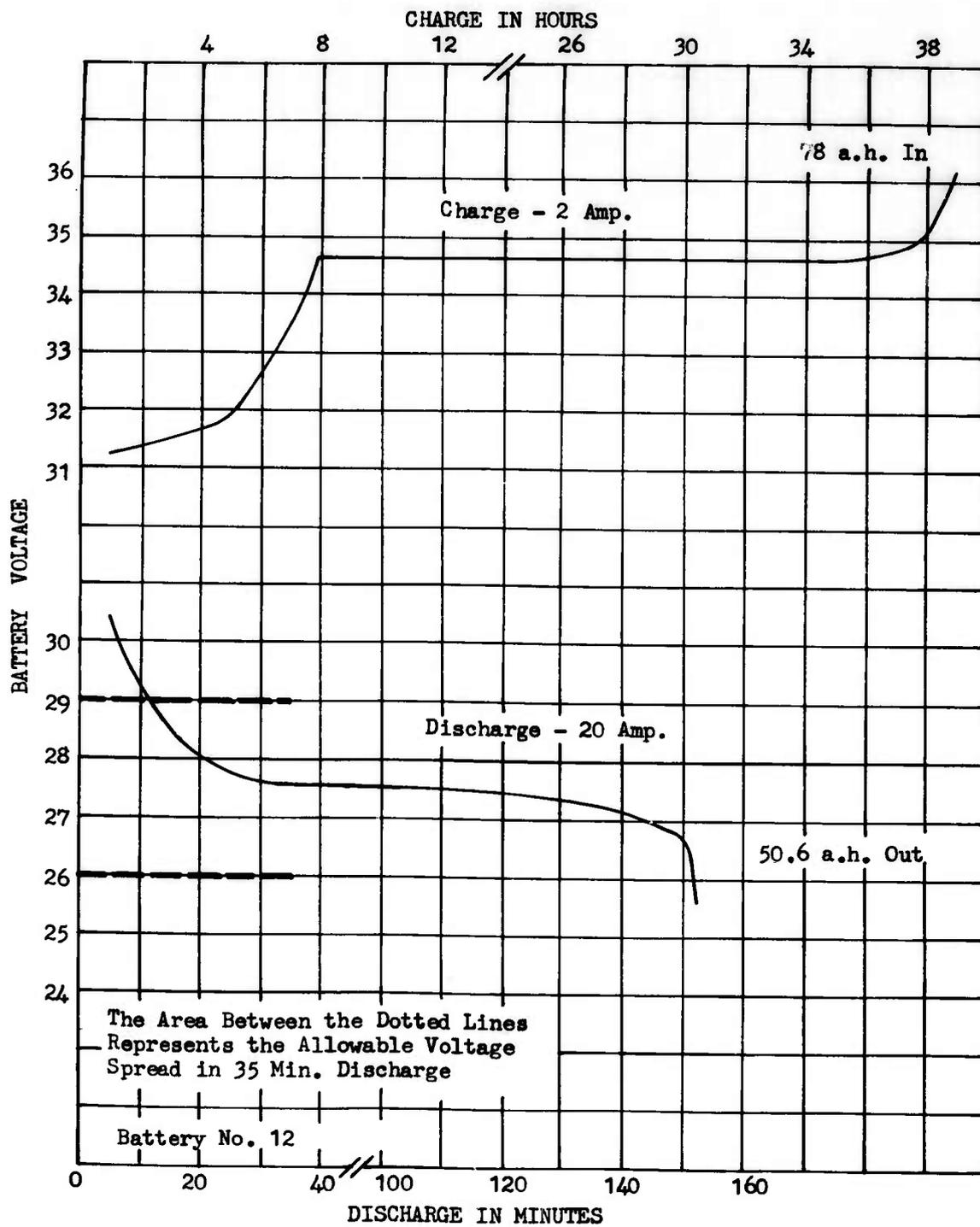


Sealed Battery No. 10  
 INITIAL CHARGE AND DISCHARGE  
 FIGURE 45



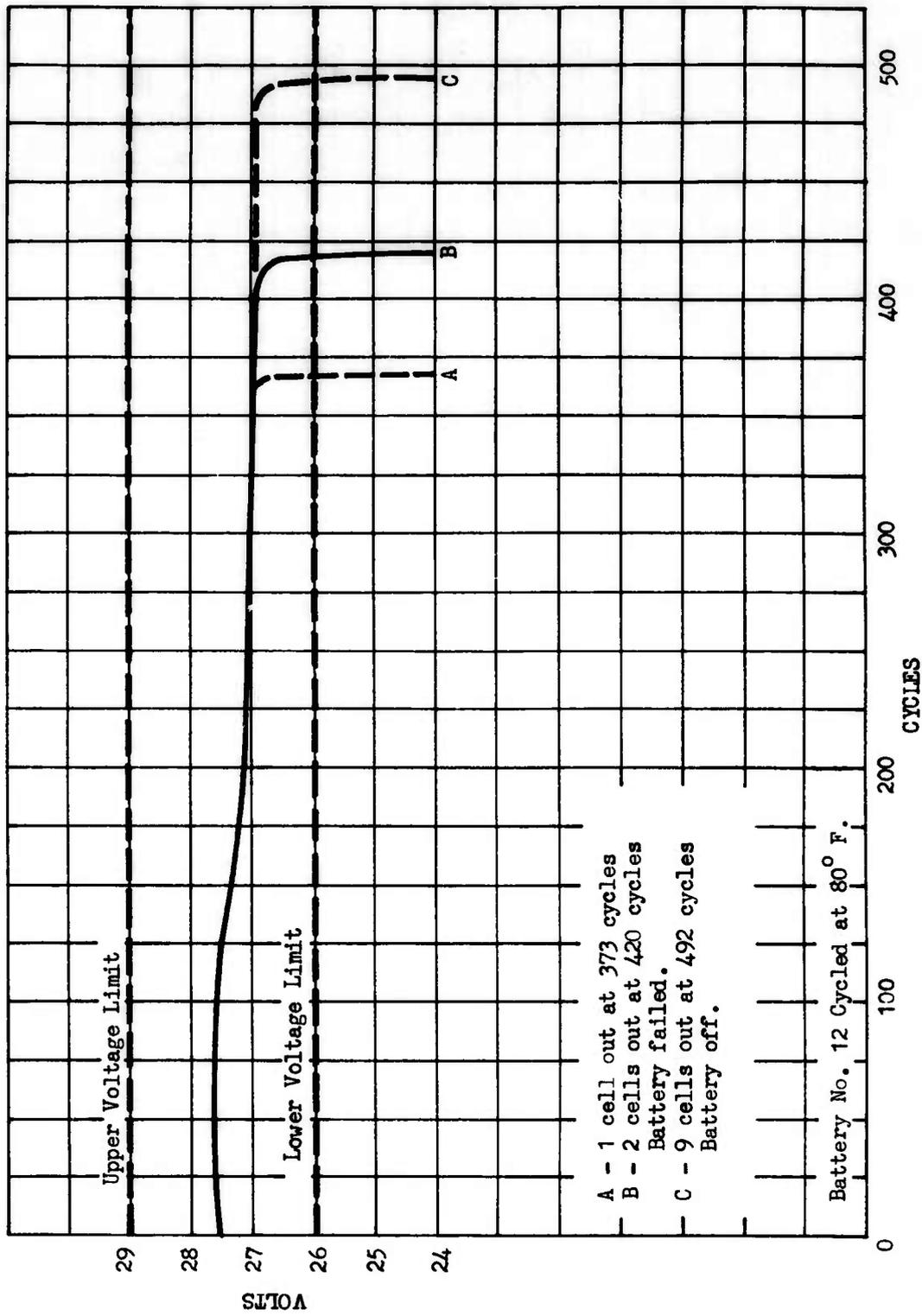
END OF DISCHARGE VOLTAGES

FIGURE 46



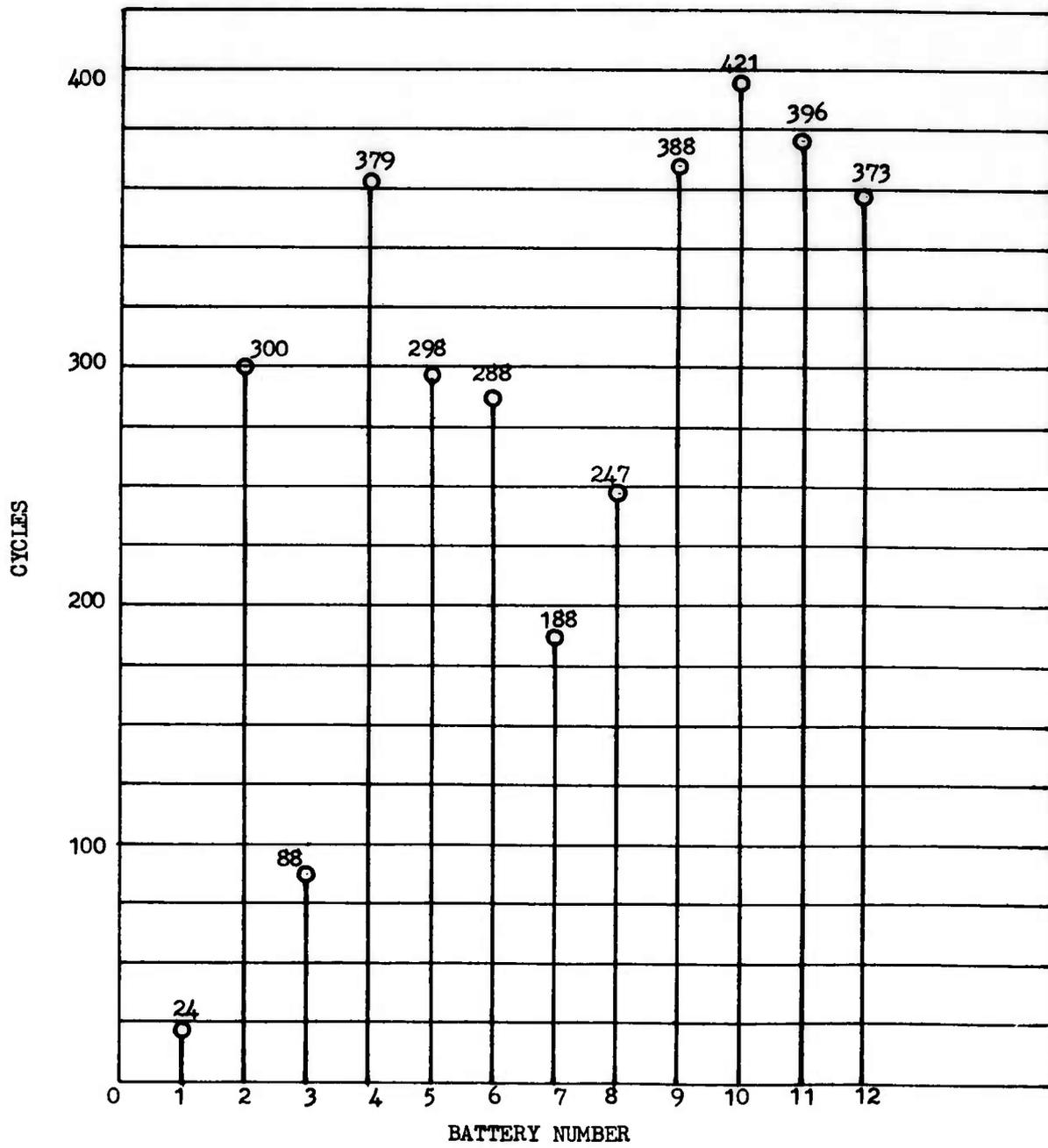
INITIAL CHARGE AND DISCHARGE

FIGURE 47



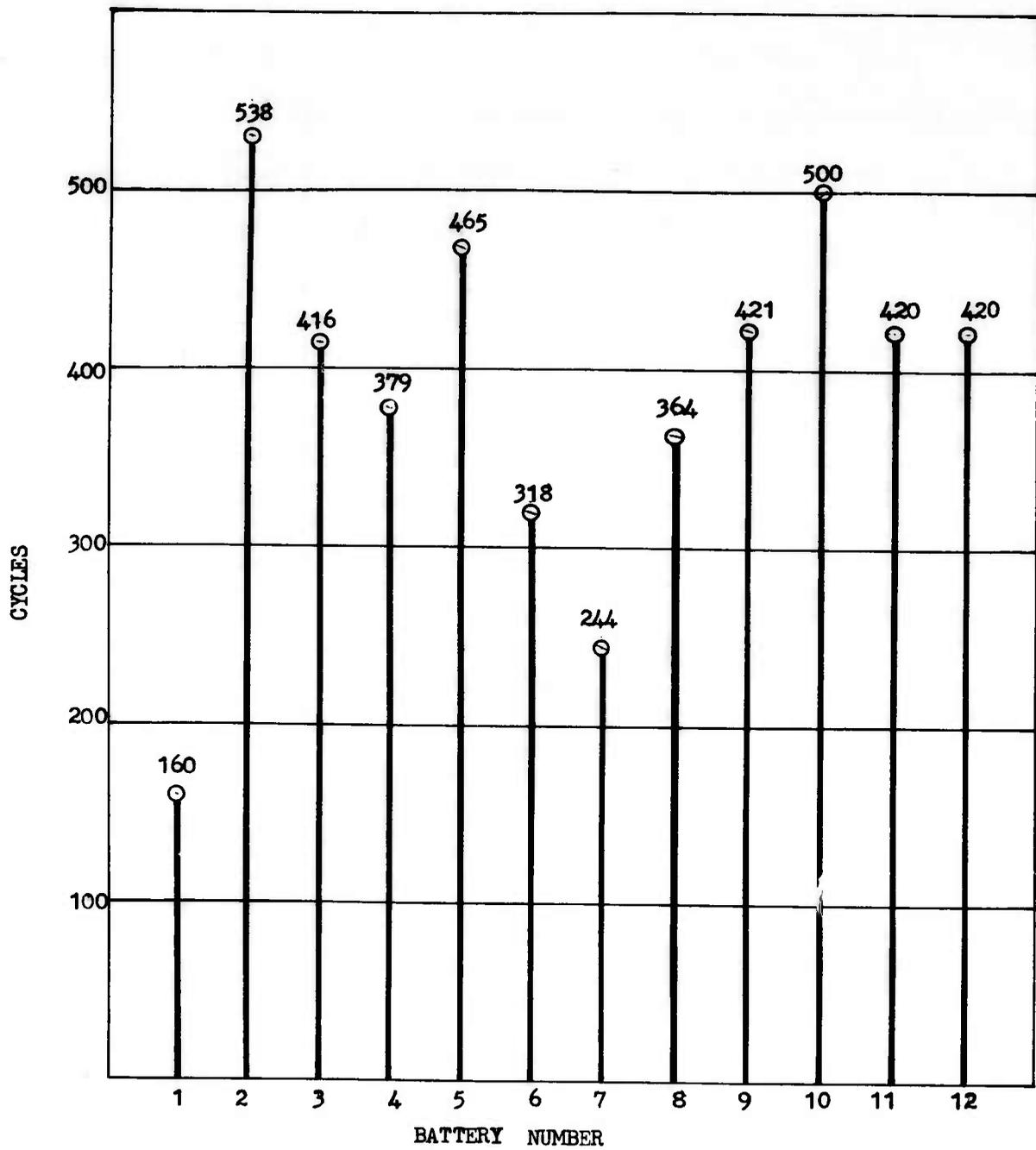
END OF DISCHARGE VOLTAGES

FIGURE 48



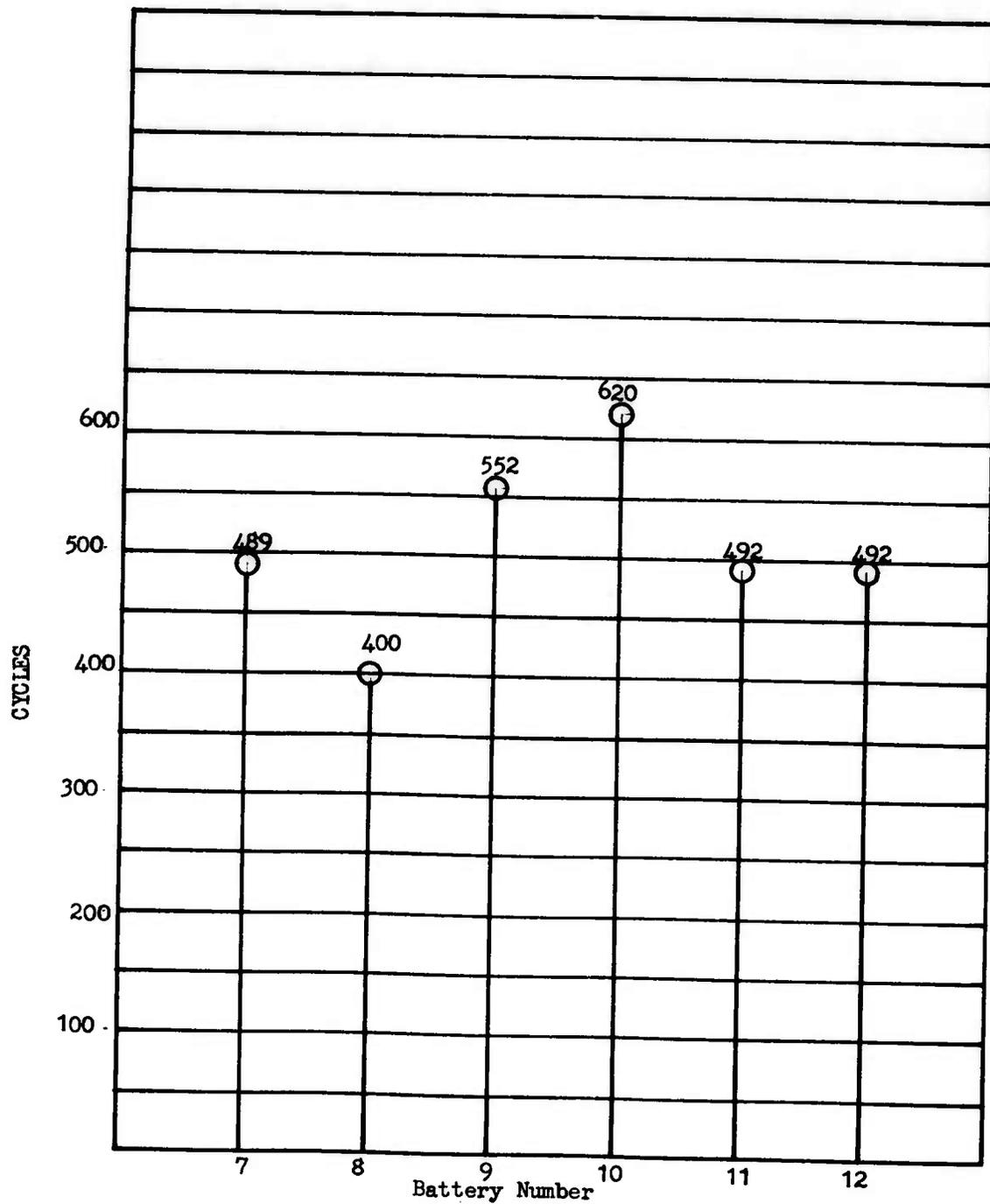
NUMBER OF CYCLES BATTERIES REACHED BEFORE A CELL FAILURE/BATTERY

FIGURE 49



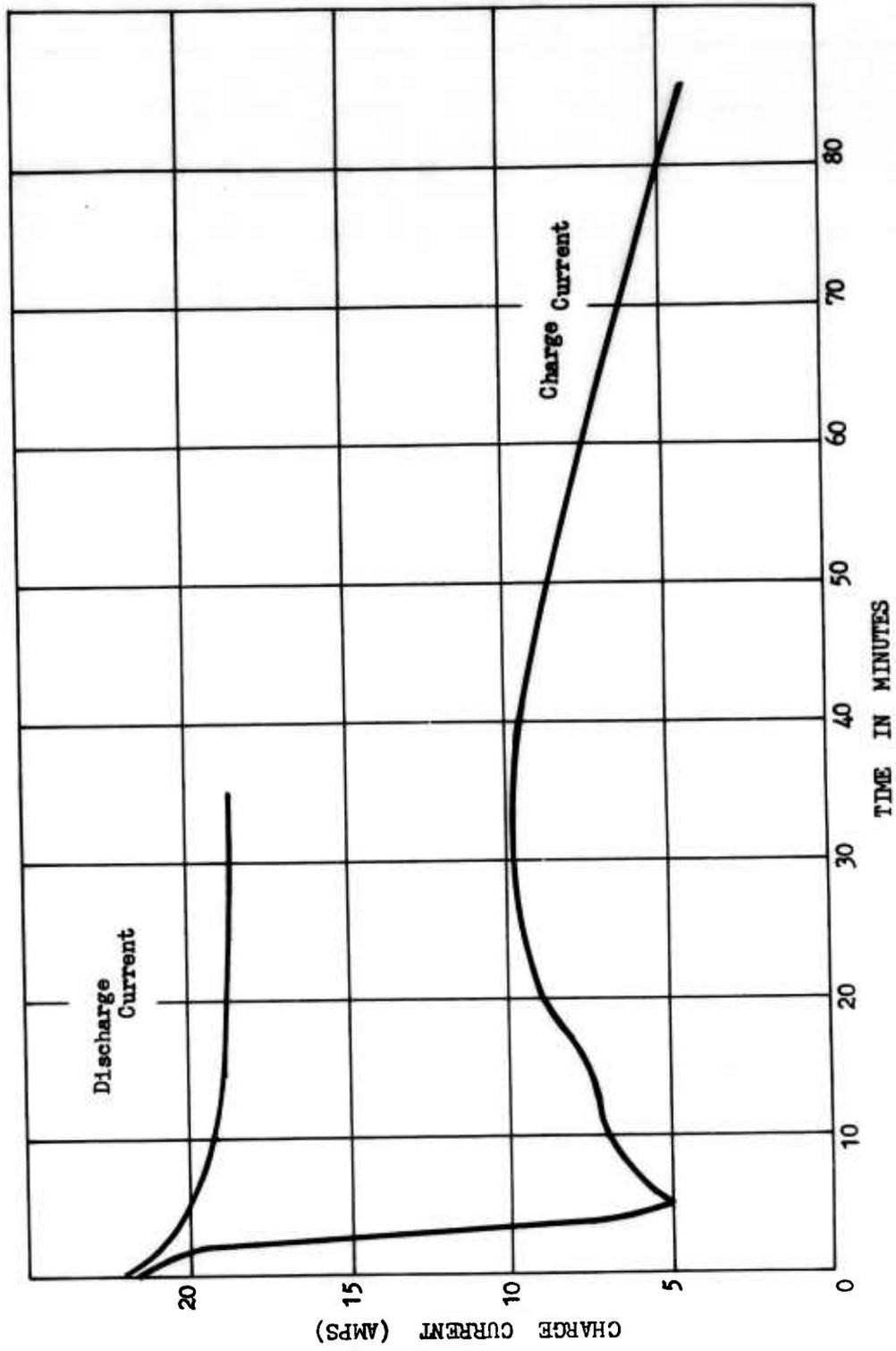
NUMBER OF CYCLES OBTAINED BY BATTERIES BEFORE FAILURE. A BATTERY FAILURE IN THIS PROGRAM IS DESIGNATED BY THE LOSS OF THREE CELLS PER BATTERY

FIGURE 50



NUMBER OF CYCLES OBTAINED BY BATTERIES AFTER 9 CELLS FAILED

FIGURE 51



TYPICAL CHARGE AND DISCHARGE CURRENT CURVES

FIGURE 52

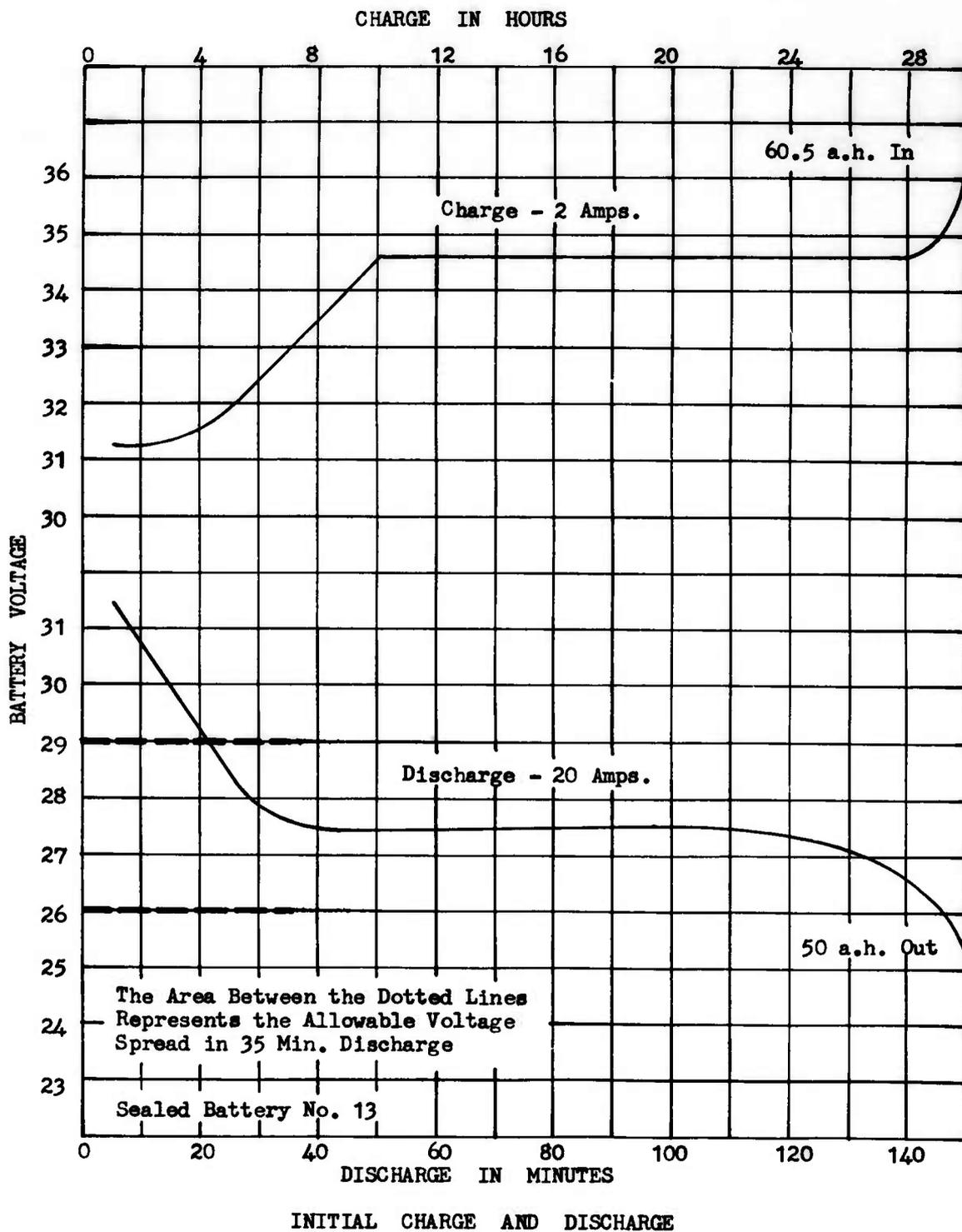


FIGURE 53

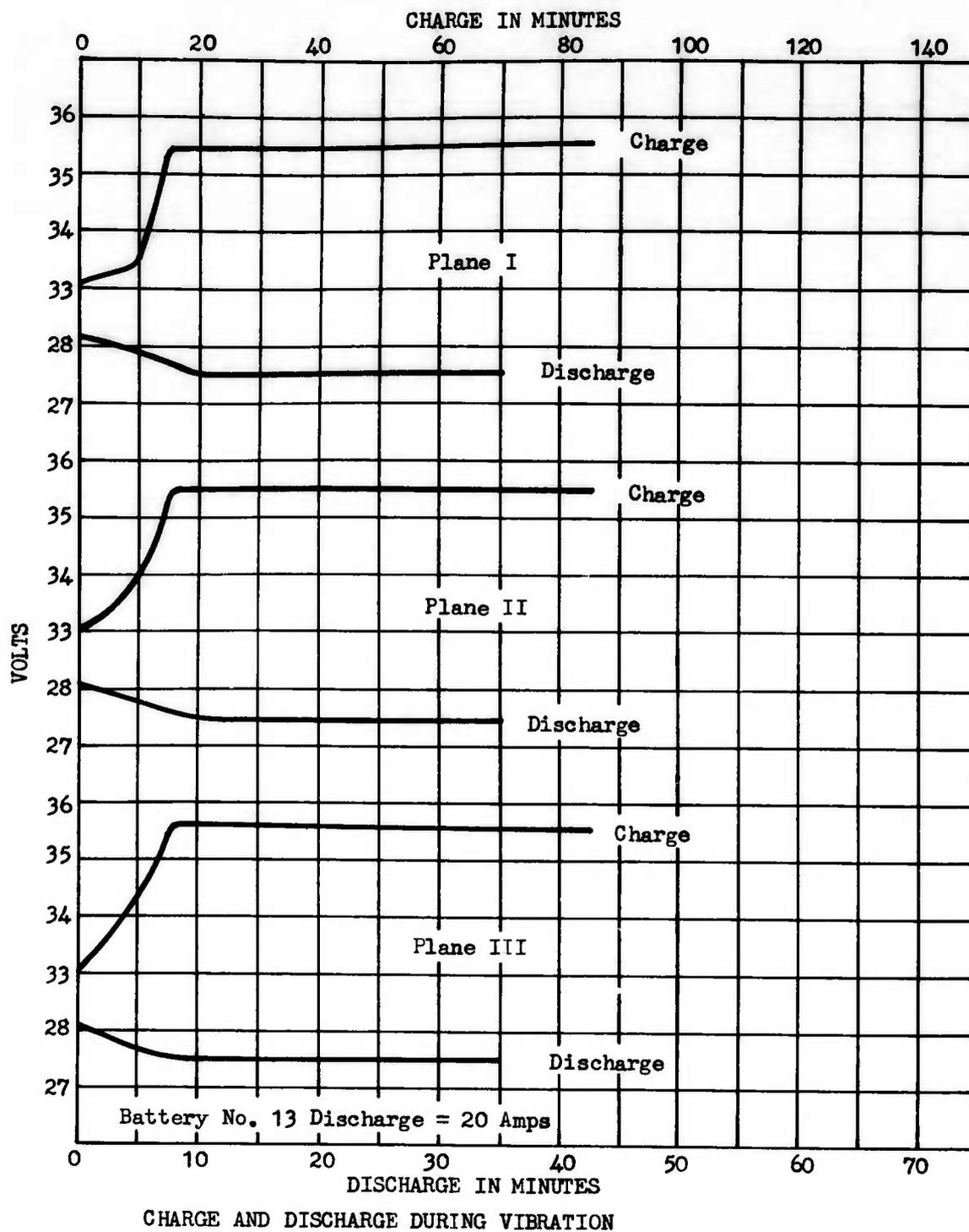


FIGURE 54

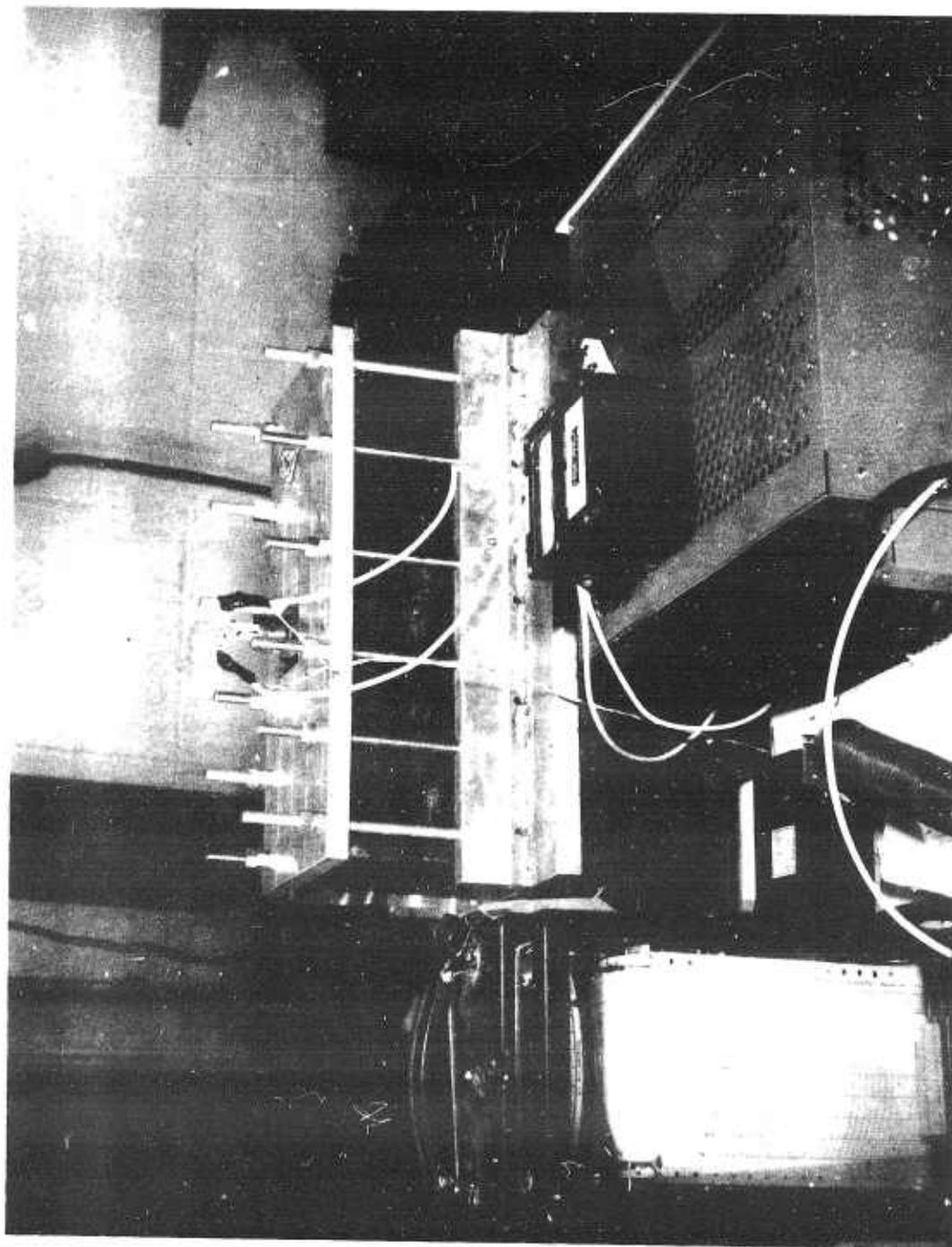
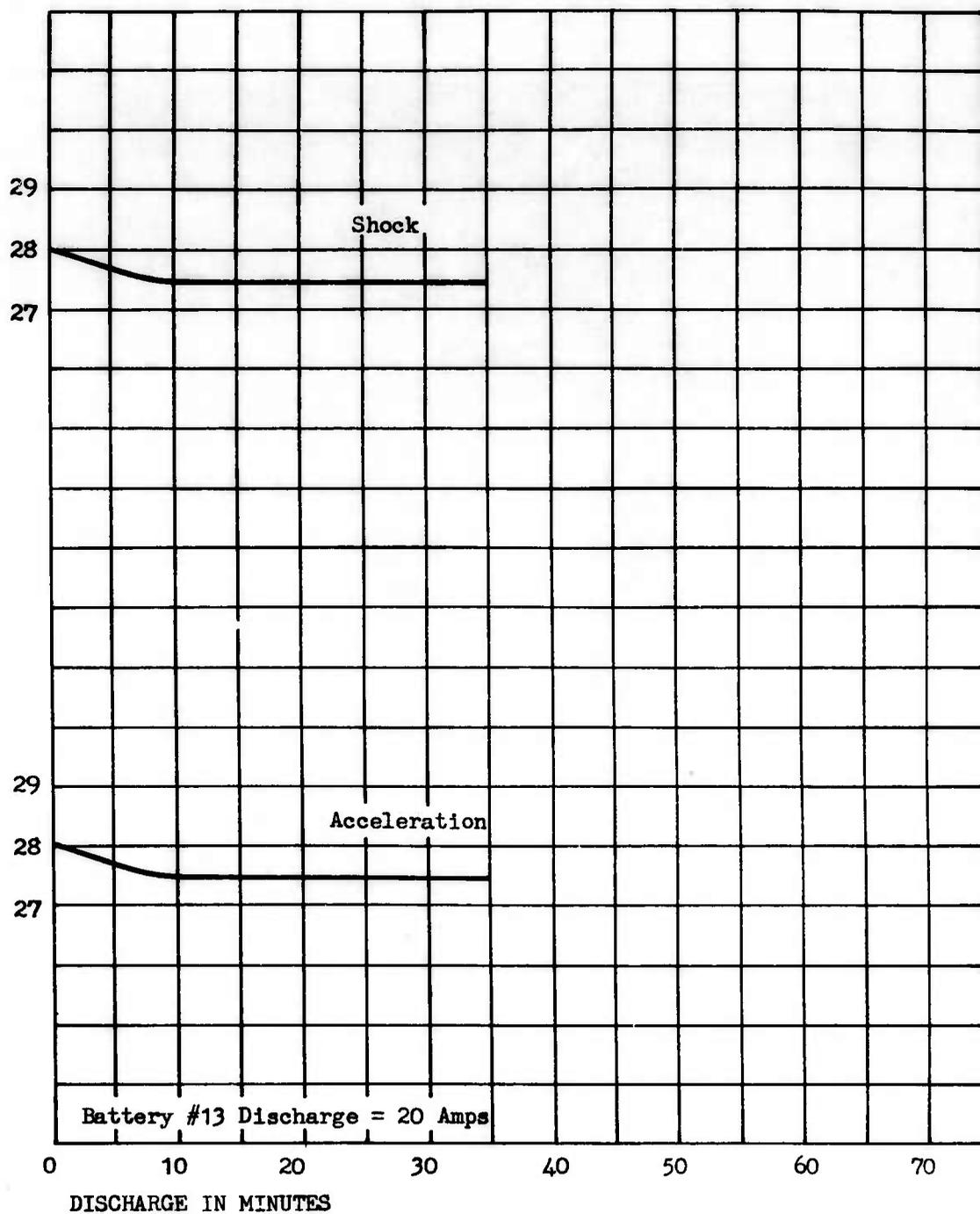


Figure 55. Vibration Test



DISCHARGE DURING SHOCK AND ACCELERATION

FIGURE 56

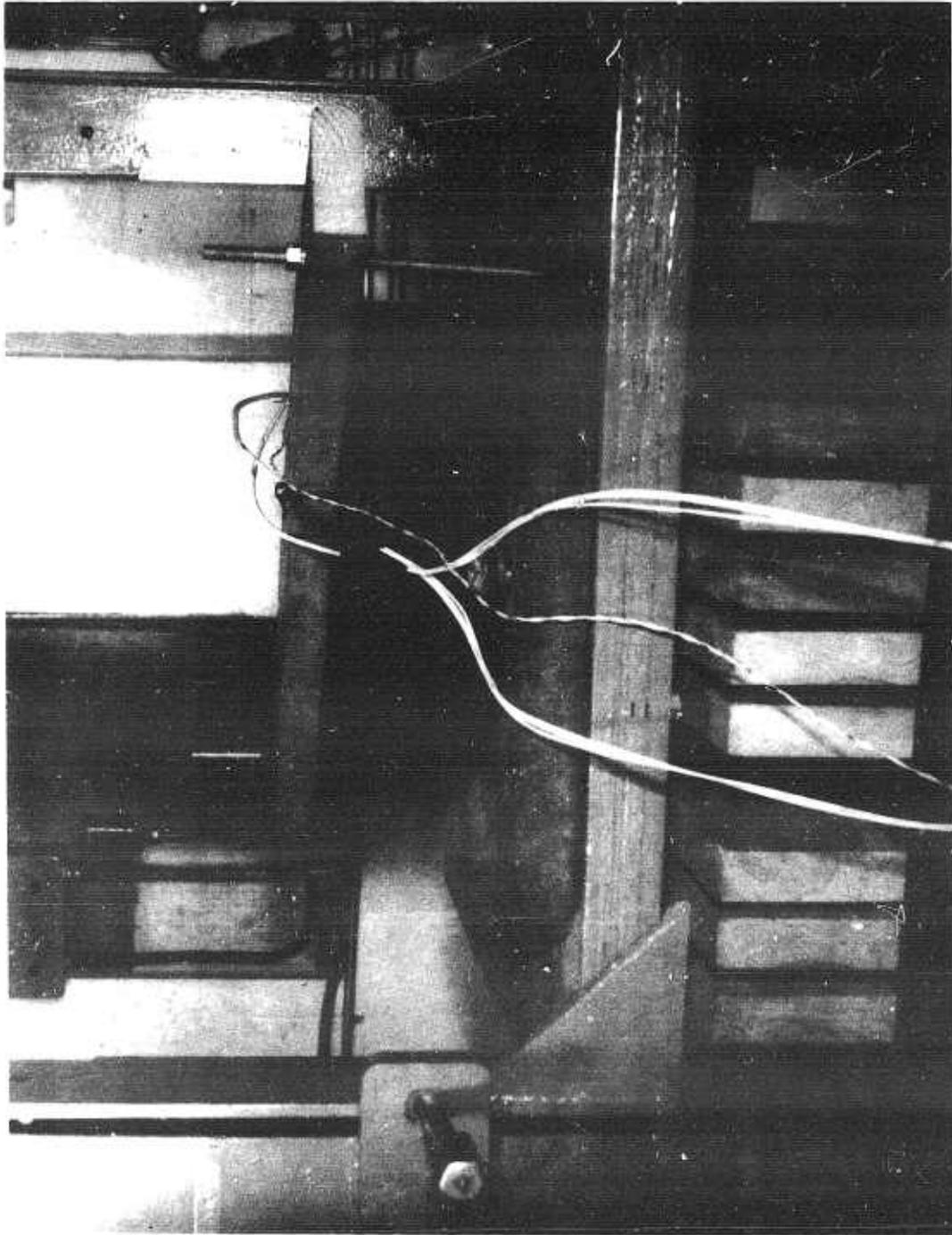


Figure 57. Shock Test

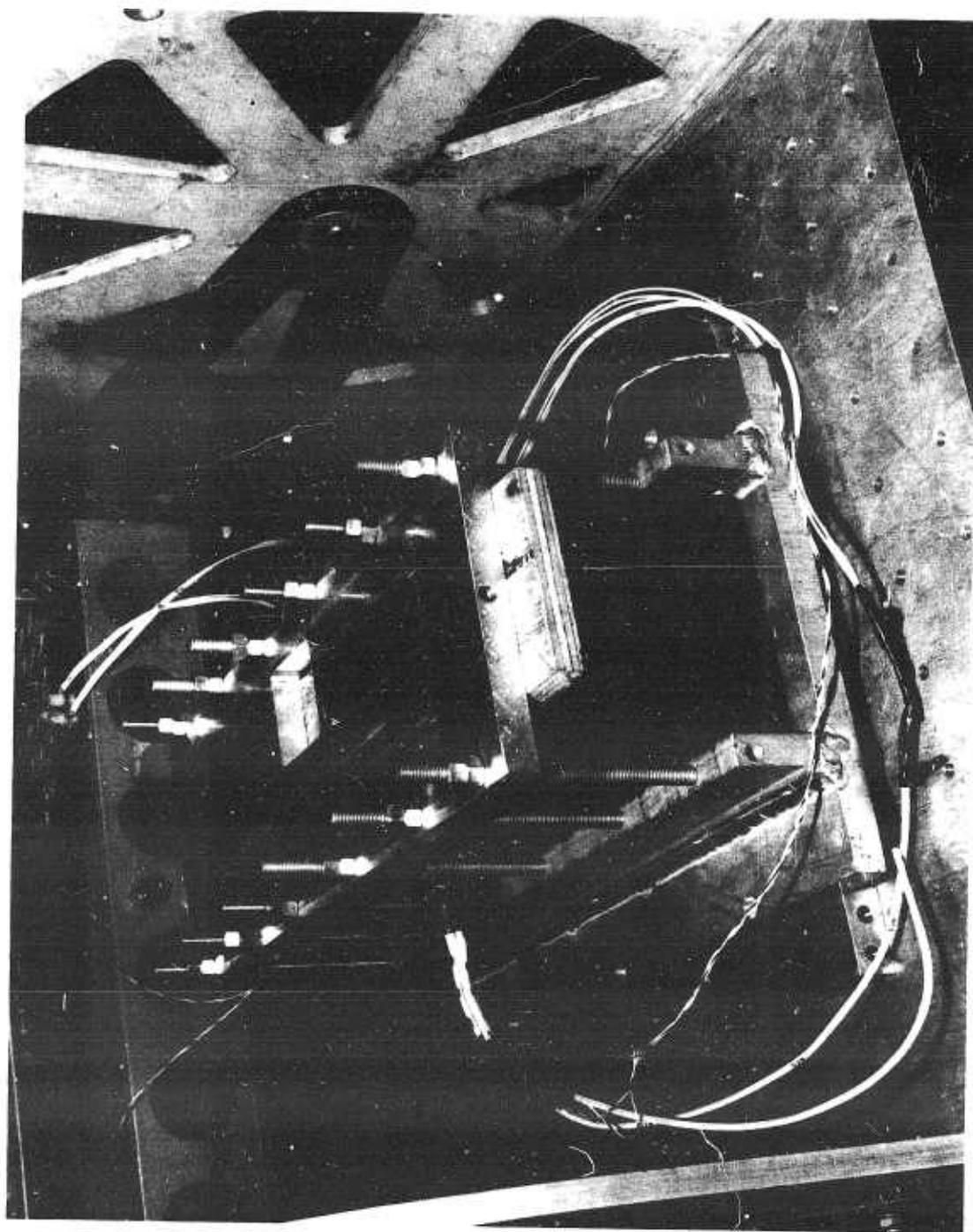
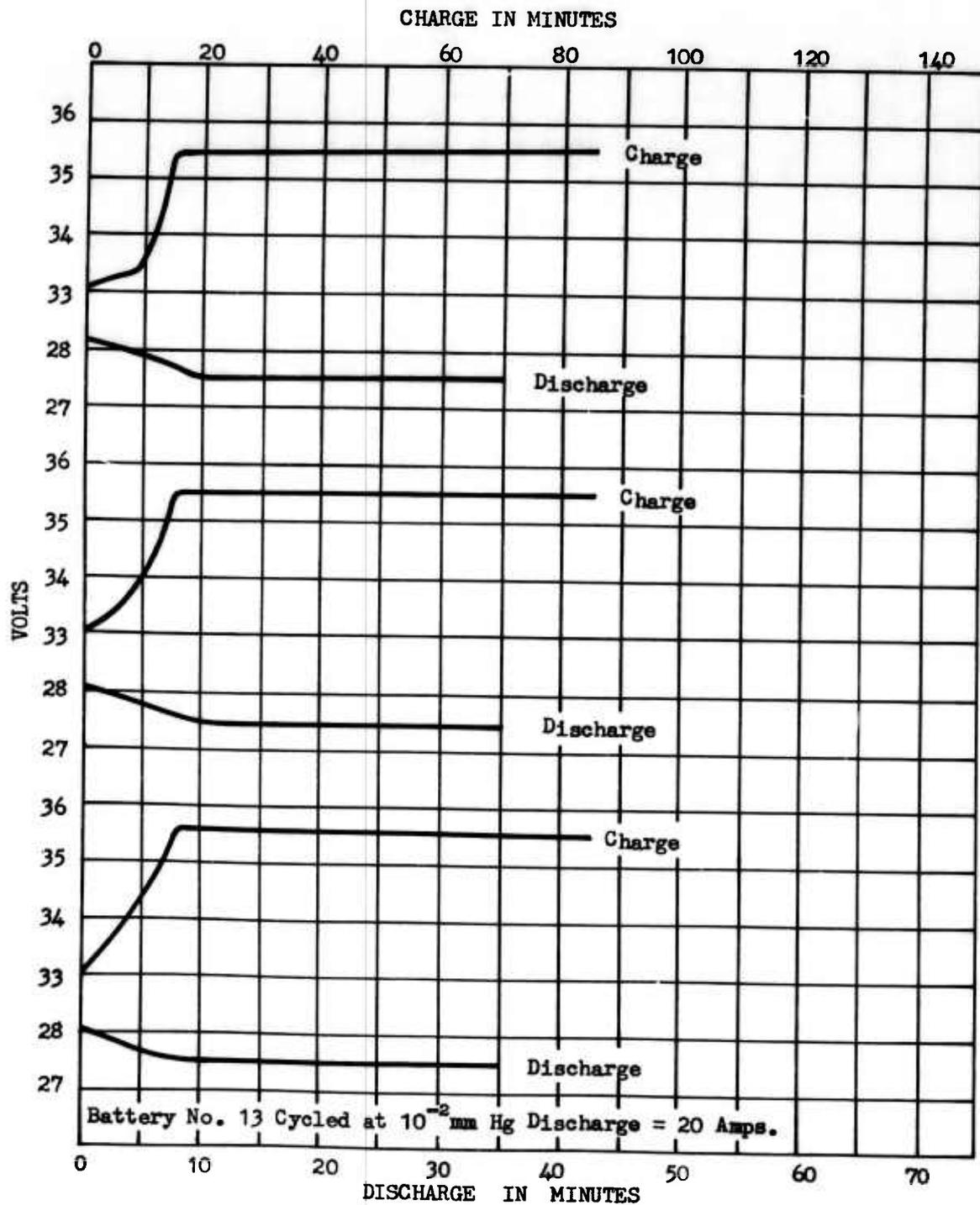


Figure 58. Acceleration Test



CHARGE AND DISCHARGE DURING VACUUM

FIGURE 59

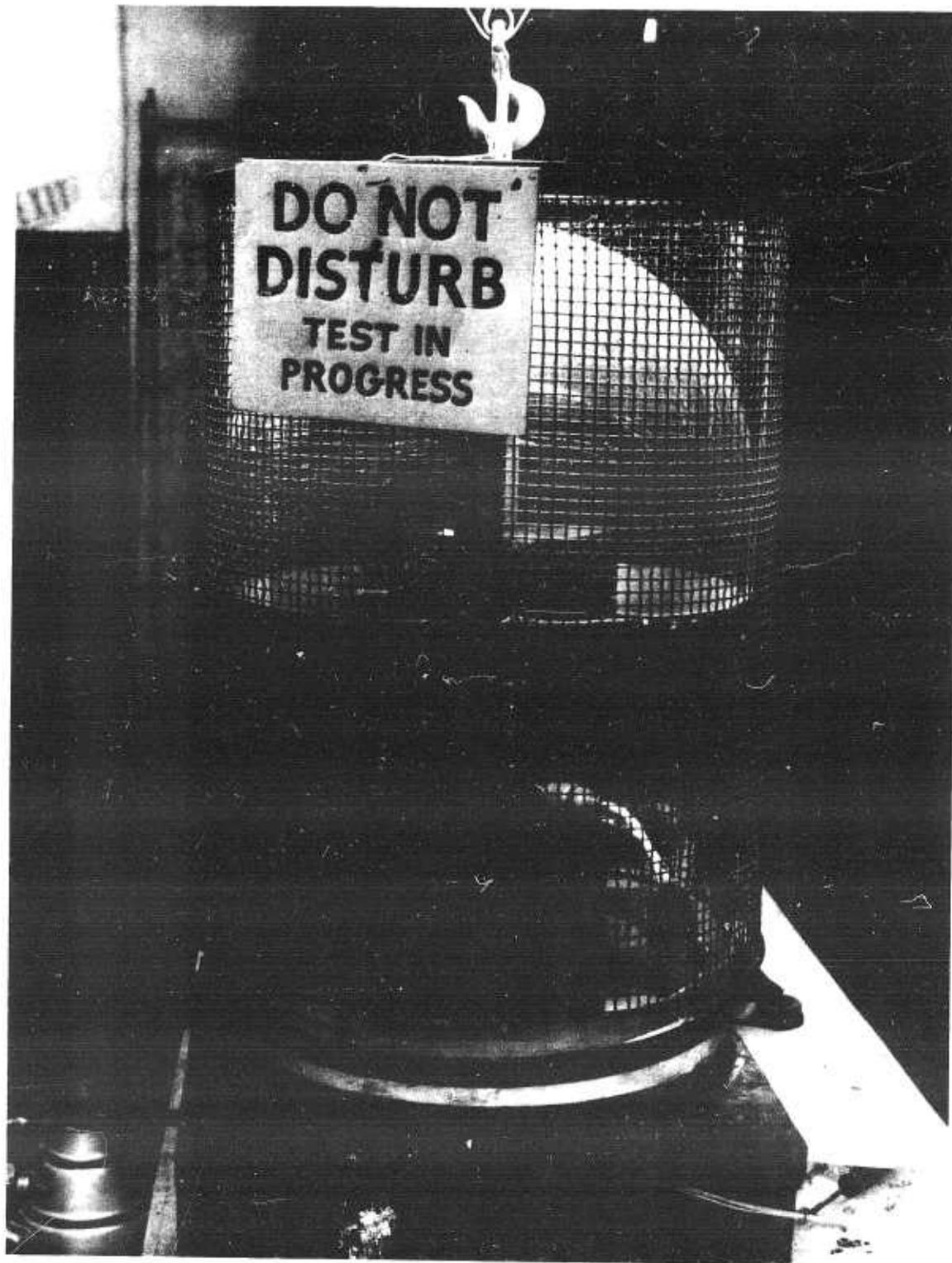


Figure 60. Vacuum Test

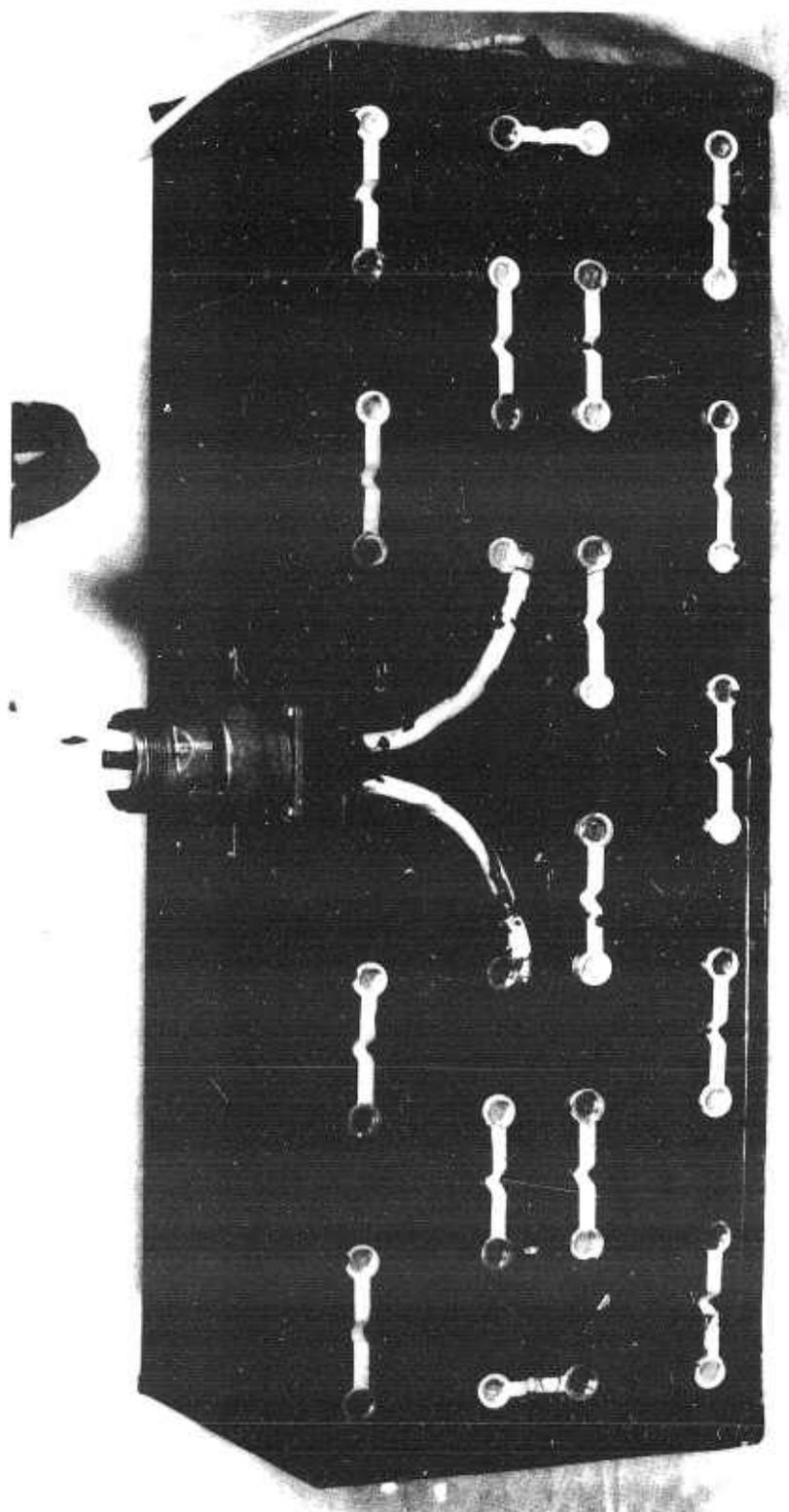


Figure 61. Battery After Completion of All Tests

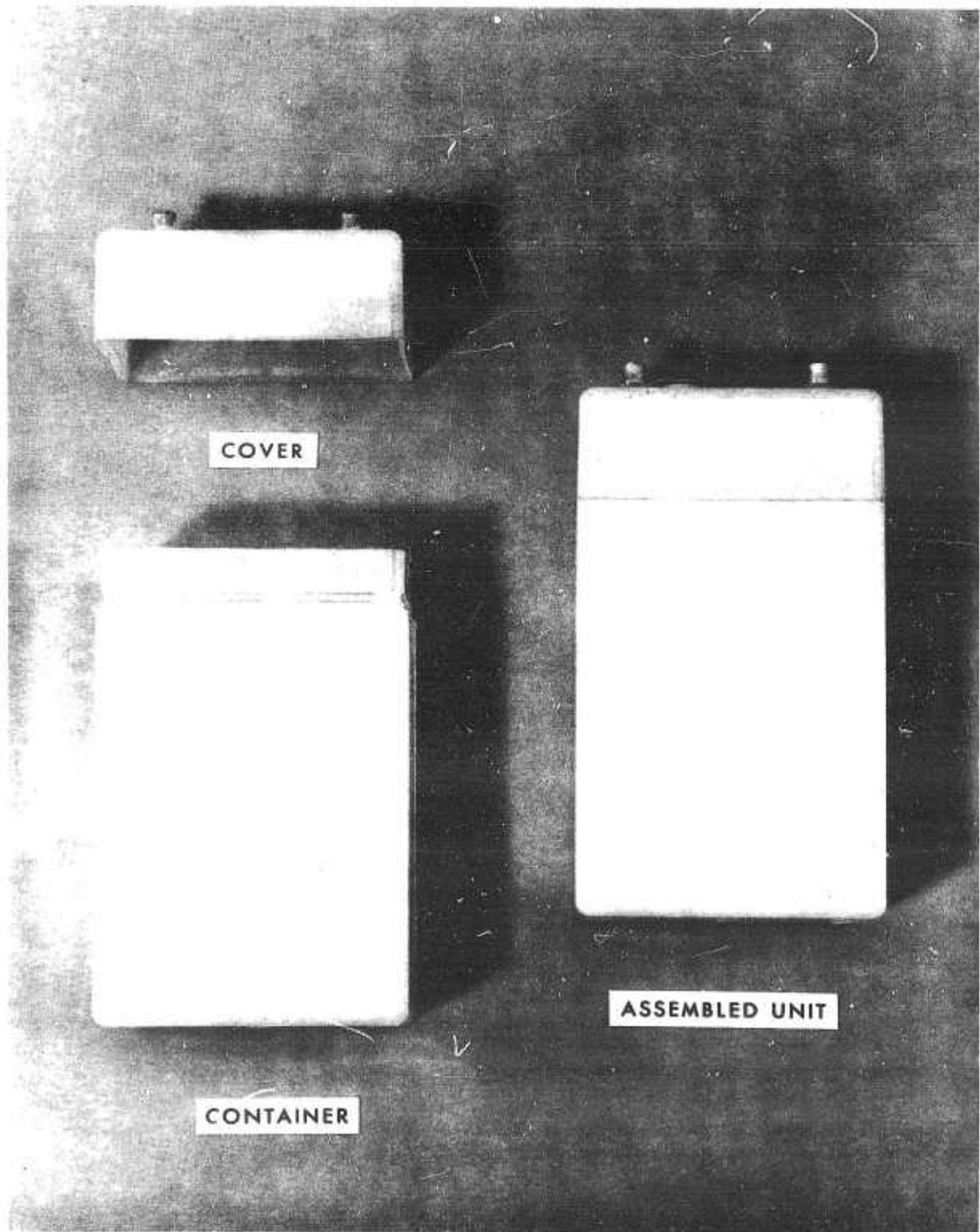


Figure 62. Cell Component and Cell Assembly - New Design

TABLE 2

All Batteries Contain 18 Cells, Activated in 40% KOH with a Total Weight of 40 to 42 Pounds, Discharge at 20 Amperes, Recharge at Constant Potential to 1.97vpc, Representing a 24% Depth of Discharge with an Operating Current Density of .052 A/in<sup>2</sup>

Battery No.	Positive Plate	Negative Plate	Separator	Electrolyte/Cell
1	.010" Ag. 19 plates	.035" - PVA as binder material 20 plates	1 layer Dynel 2 layers polyethylene base 3 layers FSC	150 c.c.
2	.010" Ag. 19 plates	.035" - PVA as binder material 20 plates	1 layer Dynel 3 layers FSC Control battery	190 c.c.
3	.010" Ag. 19 plates	.035" - PVA as binder material 20 plates	1 layer Dynel 4 layers Cellophane	200 c.c.
4	.010" Ag. 19 plates	.035" - Polyethylene oxide as binder 20 plates	1 layer Dynel 3 layers FSC	190 c.c.
5	.010" Ag. 19 plates	.035" - PVA as binder material 20 plates	2 layers Dynel 3 layers FSC	180 c.c.
6	.010" Ag. 19 plates	.035" - PVA as binder material 20 plates	1 layer Dynel 1 layer polyethylene base 3 layers FSC	180 c.c.

TABLE 3

All Batteries Contain 18 Cells, Activated in 40% KOH, Total Weight of 40 to 42 Pounds, Discharged at 20 amperes, Recharged at Constant Potential to 1.97 VPC, Representing a 24% Depth of Discharge with an Operating Current Density of .052 A/in<sup>2</sup>

<u>Battery No.</u>	<u>Positive Plate</u>	<u>Negative Plate</u>	<u>Separator</u>	<u>Electrolyte Per Cell</u>	<u>Cycle Temp.</u>
7	.010" Ag. 19 plates	.035" ZnO - PVA as binder 20 plates	1 layer Dynel 6 layers cello- phane	185	R.T.
8	"	"	"	190	100° F
9	"	"	1 layer Dynel 3 layers FSC	190	50° F
10	"	"	"	190	50° F
11	"	"	"	190	100° F
12	"	"	"	190	R.T.
13	"	"	"	150	R.T.

Battery #13 Subjected to Environmental Testing.

TABLE 4

## TEAR-DOWN DATA FOR BATTERY #1 - FAILED AT 160 CYCLES

Note: The condition of plates, separators and silver deposition indicated: an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of Separators	Positive Plates	Creeping	Negative Freeing	Plates Material Loss	Ag Penetration in Mg/in <sup>2</sup>					
								1st Dysel	2nd Poly.	3rd Poly.	4th FSC	5th FSC	6th FSC
1	1.85	Leak	Good	Formed	2 layers separa.	Tops of separa.	5%	2.35	17.65	2.80	2.30	Trace	0
2	1.82	Leak	Fair	Partially Formed	"	"	"	3.90	17.00	1.20	.30	"	0
3	1.82	Sealed	Good	"	"	"	"	2.90	18.15	1.45	.60	"	0
4	1.82	Leak	Good	"	"	"	"	2.00	15.10	1.45	.60	.25	0
5	1.85	Sealed	"	Formed	"	Tops & Sides	"	2.40	19.00	1.00	.30	Trace	0
6	1.83	"	"	Formed	"	"	"	2.30	17.00	2.00	.60	"	0
7	1.76	Leak	"	Partially Formed	3 layers separa.	"	"	7.80	20.00	.60	.10	"	0
8	1.83	"	"	Formed	"	"	"	3.75	19.80	1.25	.30	"	0
9	1.69	"	"	Partially formed	"	"	"	2.40	16.40	3.80	.70	.20	0
10	1.69	"	"	"	2 layers separa.	"	"	1.90	19.70	1.50	.30	Trace	0
11	1.68	"	"	"	"	"	"	1.70	16.70	2.80	.40	"	0
12	1.64	"	"	"	"	"	"	3.70	20.00	.80	.30	0	0
13*	1.81	"	"	Formed	"	Tops & bottoms	"	3.85	19.80	1.80	.30	Trace	0
14	1.83	"	"	Formed	3 layers Separ.	"	"	4.35	17.25	.90	.40	"	0
15	1.81	"	"	Partially formed	"	"	"	3.80	12.50	.80	.20	0	0
16	1.75	"	"	"	"	"	"	4.85	20.55	1.20	.60	Trace	0
17*	1.59	"	Poor	"	"	"	"	5.00	18.75	.90	.25	"	0
18*	1.64	"	Poor	"	"	"	"	3.25	17.65	1.00	.50	"	0

\* Cells that failed.

TABLE 5

## TEAR-DOWN DATA FOR BATTERY #2 - FAILED AT 538 CYCLES (CONTROL BATTERY)

Note: The condition of plates, separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Circuit Condition of Cell Case	Condition of Separators	Positive Plates	Creeping	Negative Plates Tree-ing	Material Loss	Ag Penetration in Mg/in <sup>2</sup>			
								1st Dynel	2nd FSC	3rd FSC	4th FSC
1	1.85	Leak	Good	Formed	Around 2 layers	Sides & tops	15%	4.1	64.4	5.4	.2
2	1.85	"	"	"	"	Side, top & bottom	30%	5.6	69.8	.15	trace
3	1.56	"	"	Partially formed	"	"	30%	5.1	71.9	.32	0
4	1.85	"	"	Formed	"	"	30%	4.2	56.5	.75	.11
5	1.85	Sealed	"	Formed	"	"	40%	2.6	60.8	.86	.22
6	1.85	Leak	"	"	"	"	35%	3.5	58.1	.68	.11
7	1.85	"	"	"	"	"	40%	3.8	63.2	.43	trace
8	1.85	"	"	"	"	"	25%	3.8	69.3	.86	.22
9	1.84	Sealed	"	"	"	"	30%	4.1	76.6	.54	trace
10 *	1.84	Leak	"	"	"	"	35%	4.3	66.3	.32	"
11 *	1.66	"	"	Partially formed	"	"	25%	5.6	77.6	.54	"
12	1.68	"	"	"	"	"	25%	7.0	89.9	.32	"
13 *	1.60	"	"	"	"	"	50%	8.3	76.8	.32	0
14	1.85	"	"	Formed	"	"	35%	3.2	57.0	1.1	.22
15	1.85	"	"	"	"	"	20%	3.9	63.4	.54	trace
16	0.00	"	"	discharged	"	"	35%	5.7	87.9	.75	"
17	1.85	"	"	Formed	"	"	25%	6.8	82.4	.75	.32
18	0.00	"	"	Discharged	"	"	30%	4.4	53.4	.86	trace

\* Cells that failed.

TABLE 6

## TEAR-DOWN DATA FOR BATTERY # 3 - FAILED AT 416 CYCLES

Notes: The condition of plates, separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of Separators	Positive Plates	Creeping	Negative Plates Treating	Mat'l Loss	Ag Penetration in Mg/in <sup>2</sup>				
								1st Dymel	2nd Cello	3rd Cello	4th Cello	5th Cello
1	1.05	Leak	Good	Partially formed	None	Tops	50-60%	5.3	52.2	.9	.3	0
2	1.86	"	"	Formed	Around 2 layers	"	15%	2.9	40.6	.6	.7	.3
3	1.86	Sealed	"	Formed	"	"	10%	3.2	50.1	2.1	.4	.3
4	1.71	Leak	"	Partially formed	"	"	30%	5.4	53.6	1.2	.3	trace
5	1.57	Sealed	"	"	"	"	10%	4.9	54.1	1.0	.4	0
6	1.72	"	"	"	"	"	15%	4.3	42.2	2.2	.5	.3
7	1.85	Leak	"	Formed	"	"	10%	4.5	27.9	1.5	1.0	.3
8	1.68	"	"	Partially formed	"	"	35%	4.7	53.8	1.0	.4	.3
9	1.85	"	"	Formed	"	"	40%	4.8	52.0	1.7	.4	.2
10*	0.18	"	"	Discharged	None	"	10%	5.4	59.3	3.5	1.0	trace
11	1.59	"	"	Partially formed	Around 2 layers	"	20%	5.2	61.0	1.0	.6	trace
12*	1.07	"	"	"	"	"	15%	5.4	51.0	2.8	1.2	.7
13	1.85	"	"	Formed	"	"	10%	5.0	45.8	2.8	1.0	.3
14	1.83	Sealed	"	"	"	"	30%	5.0	48.5	3.0	.5	.8
15*	0.00	Leak	"	Discharged	None	"	10%	2.6	25.0	.4	trace	0
16	1.85	"	"	Formed	Around 2 layers	"	10%	3.8	56.5	2.5	.5	.3
17	1.58	"	"	Partially formed	"	"	25%	5.9	53.8	1.0	.3	trace
18	1.83	Sealed	"	Formed	"	"	5%	3.8	64.2	2.2	.8	.4

\* Cells that failed.

TABLE 7

## TEAR-DOWN DATA FOR BATTERY #4 (Failed 379 Cycles)

Note: The Condition of Plates, Separators and Silver Deposition Indicate an Average Per Cell.

Cell No.	Open Voltage after Charge	Circuit Condition of Cell Case	Condition of Separators	Positive Plates	Formed	Negative Plates		Ag Penetration in Mg/in <sup>2</sup>				
						Creeping	Treeing	Mat'l Loss	1st Dynel	2nd FSC	3rd FSC	4th FSC
1	1.85	Sealed	Good		Formed	Around 1 layer	none	10%	2.4	57.6	.8	trace
2	1.85	Leak	"		"	Around 2 layers	"	5%	3.0	57.2	.7	"
3	1.85	Sealed	"		"	Around 2 layers	"	none	3.8	51.6	.5	"
4	1.84	Leak	"		"	Around 1 layer	"	"	4.2	48.7	.9	"
5	1.85	Leak	"		"	"	"	"	4.1	52.9	.7	"
6 *	1.86	Leak	"		"	"	"	"	2.9	55.7	.3	"
7 *	1.84	Sealed	"		"	Around 2 layers	Some	"	5.5	51.6	.4	"
8 *	1.85	Leak	"		"	"	Some	"	5.3	56.0	.3	0
9	1.85	"	"		"	"	None	"	3.1	58.6	.6	trace
10 *	1.85	"	"		"	"	"	"	2.9	57.6	.5	trace
11	1.85	"	"		"	"	"	"	3.7	60.4	.7	trace
12	1.85	"	"		"	"	"	"	4.7	53.5	.7	trace
13	1.85	"	"		"	"	"	10%	3.0	53.3	.6	trace
14	1.85	"	"		"	"	"	none	3.0	53.8	.7	trace
15	1.85	"	"		"	"	"	"	2.4	48.0	.8	trace
16	1.85	"	"		"	"	"	"	3.4	51.2	.6	trace
17 *	1.85	Sealed	"		"	"	"	"	3.2	50.5	.2	0
18	1.85	Leak	"		"	"	"	"	3.5	47.3	.8	0

\* Cells that failed.

TABLE 8

## TEAR-DOWN DATA FOR BATTERY #5 - FAILED 465 CYCLES

Notes: The condition of plates and separators and silver deposition merely indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of Separators	Positive Plates	Creeping	Negative Plates		Ag Penetration in Mg/in <sup>2</sup>						
						Around 2 layers	Top of	Mat'l	1st layer	2nd	3rd	4th	5th	
				Partially formed		Treeing	Loss	Dynel	Dynel	FSC	FSC	FSC	FSC	FSC
1	1.57	Sealed	Good	Partially formed			10%	2.9	2.1	46.34	.43	trace		
2	1.85	Leak	"	Formed	"		20%	4.5	3.2	47.1	.43	.22		
3	1.85	"	"	"	"		10%	1.6	3.3	44.2	.75	.22		
4	1.30	"	"	Partially formed	"		15%	2.6	1.8	44.0	.86	.32		
5	1.67	"	"	"	"		10%	2.2	1.8	45.4	.22	trace		
6	1.68	Sealed	"	"	"		10%	3.2	5.1	52.7	.32	"		
7	1.86	Leak	"	Formed	"		25%	4.5	4.2	47.4	.43	"		
8	1.58	Sealed	"	Partially formed	"		20%	7.4	4.5	33.6	.22	"		
9	1.86	Leak	"	Formed	"		30%	4.9	4.0	55.1	.86	.22		
10*	1.57	"	"	Partially formed	"		10%	9.2	3.9	33.3	.11	none		
11	1.81	"	"	"	"		15%	4.3	3.9	48.7	.43	.22		
12*	0.00	"	"	Totally discharged	"		30%	4.5	2.9	51.5	.11	none		
13	1.86	"	"	Formed	"		30%	3.9	3.8	46.1	.69	.22		
14	1.86	"	"	Formed	"		20%	3.6	4.1	34.9	.64	.22		
15	1.79	"	"	Partially formed	"		15%	2.2	2.0	47.7	.75	.43		
16	1.85	"	"	Formed	"		12%	4.0	3.6	44.2	.96	.32		
17	1.76	"	"	Partially formed	"		10%	6.8	5.2	41.5	.75	.32		
18*	0.00	"	"	Totally Discharged	"		35%	6.5	3.7	37.3	.22	.32		

\* Cells that failed.

TABLE 9

## TEAR-DOWN DATA FOR BATTERY #6 - FAILED 318 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of Separators	Positive Plates	Negative Plates		Mat'l Loss	1st Dynel Poly. Pass	Ag Penetration in Mg/in <sup>2</sup>			5th FSC
					Creeping	Trees & Tops			2nd layer	3rd	4th	
1	1.85	Sealed	Good	Formed	Around 2 layers	Tops & sides	50%	2.1	27.6	.7	-	-
2	1.85	Leaked	"	"	"	"	50%	2.5	30.4	.2	-	-
3 *	1.59	Sealed	"	Partially formed	"	"	60%	3.1	26.6	.2	-	-
4	1.85	Leaked	"	Formed	"	Tops	50%	1.4	27.8	.4	-	-
5	1.84	Leaked	"	"	"	"	50%	2.0	28.5	.3	-	-
6	1.85	Sealed	"	"	"	"	50%	2.5	29.0	.3	-	-
7	1.85	"	"	"	"	"	50%	3.0	31.7	.2	-	-
8 *	1.87	"	"	"	"	"	15%	4.0	31.0	.6	trace	-
9 *	1.86	Leaked	"	"	"	"	15%	3.0	28.4	.8	-	-
10	1.85	Sealed	"	"	"	"	30%	3.1	28.6	.2	-	-
11	1.85	Leaked	"	"	"	"	30%	3.4	28.8	.1	-	-
12	1.85	Sealed	"	"	"	"	40%	3.0	26.2	.1	-	-
13	1.83	"	"	"	"	"	40%	2.0	33.0	2.0	-	-
14	1.85	"	"	"	"	"	50%	1.6	25.2	4.7	-	-
15	1.84	Leak	"	"	"	"	30%	1.7	24.9	1.2	-	-
16 *	1.85	"	"	"	"	"	70%	3.0	31.1	.5	-	-
17	1.86	"	"	"	"	"	45%	2.2	25.8	.4	-	-
18	1.84	"	"	"	"	"	35%	2.8	29.4	.2	-	-

\* Cells that failed.

TABLE 10

## TEAR-DOWN DATA FOR BATTERY #7 - FAILED 244 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Circuit Condition of Cell Case	Condition of Separators	Positive Plates	Discharge	Creeping	Negative Plates		Ag Penetration in Mg/in <sup>2</sup>							
							Creeping	Treeing	Loss	Mat'l	1st	2nd	3rd	4th	5th	6th
										Dynel	Cello.	Cello.	Cello.	Cello.	Cello.	Cello.
1*	0.00	Leaked	1st layer cellophane deteriorated	Discharge	none	sides	5%	.9	45.2	.7	.1	-	-	-	-	-
2	1.84	"	"	Formed	"	tops	15%	2.9	65.0	1.9	.5	.3	.2	.1		
3*	0.00	"	"	Discharged	"	"	5%	1.8	47.5	1.0	.2	.1	-	-		
4	1.84	"	"	Formed	"	"	15%	3.1	52.3	2.3	.6	.2	.1	.1		
5	1.84	"	"	"	"	"	15%	3.2	56.2	2.0	.4	.2	.1	.1		
6*	0.00	"	"	Discharged	"	"	15%	2.6	39.2	.5	-	-	-	-		
7	1.84	"	"	Formed	"	"	10%	2.6	55.6	2.2	.6	.2	.1	.1		
8*	0.00	"	"	Discharged	"	"	15%	1.7	45.2	7.0	.1	-	-	-		
9*	0.00	"	"	"	"	"	10%	2.1	46.8	3.0	-	-	-	-		
10*	1.83	"	"	Partially formed	"	"	15%	3.3	59.5	1.9	.4	.2	.1	.1		
11	1.84	"	"	"	"	"	15%	5.0	64.0	1.7	.4	.2	.1	.1		
12	1.84	"	"	"	"	"	10%	3.7	61.1	2.6	.5	.4	.2	.1		
13*	0.00	"	"	Discharged	"	"	15%	2.9	66.5	1.4	.6	.2	-	-		
14*	1.80	"	"	Partially formed	"	"	20%	2.5	63.0	2.0	.6	.3	.2	.1		
15*	1.83	"	"	"	"	"	15%	3.5	63.9	2.8	.5	.3	.2	.1		
16	1.85	"	"	"	"	"	15%	6.0	65.8	2.0	.5	.4	.2	.2		
17	1.85	"	"	"	"	"	"	4.0	64.7	1.4	.5	.3	.1	.1		
18	1.83	"	"	"	"	"	"	2.3	61.9	2.0	.4	.2	.1	.1		

\* Cells that failed.

TABLE 11  
BATTERY NO. 8

<u>Cell #</u>	<u>Charge</u>			<u>Discharge</u>		
	<u>20 min.</u>	<u>60 min.</u>	<u>85 min.</u>	<u>5 min.</u>	<u>20 min.</u>	<u>35 min.</u>
1	1.94	1.96	2.04	1.75	1.52	1.50
2	1.93	1.96	1.99	1.75	1.52	1.49
3	1.93	1.95	1.95	1.67	1.52	1.50
4	1.95	1.95	1.95	1.72	1.52	1.52
5	1.93	1.95	1.94	1.62	1.52	1.49
6	1.93	1.94	1.94	1.60	1.52	1.46
7	1.93	1.94	1.94	1.59	1.52	1.47
8	1.93	1.94	1.94	1.57	1.52	1.50
9	1.93	1.95	1.94	1.58	1.52	1.50
10	1.93	1.94	1.94	1.61	1.52	1.47
11	1.93	1.94	1.94	1.58	1.52	1.49
12	1.93	1.94	1.94	1.58	1.52	1.51
13	1.94	1.95	1.95	1.57	1.53	1.52
14	1.93	1.94	1.94	1.62	1.52	1.50
15	1.94	1.94	1.94	1.64	1.52	1.50
16	1.93	1.95	1.95	1.68	1.52	1.50
17	1.93	1.95	1.96	1.68	1.52	1.50
18	1.93	1.95	1.98	1.65	1.52	1.51

TABLE 12  
BATTERY NO. 11

300 Cycles

<u>Cell #</u>	<u>Charge</u>			<u>Discharge</u>		
	<u>20 min.</u>	<u>60 min.</u>	<u>85 min.</u>	<u>5 min.</u>	<u>20 min.</u>	<u>35 min.</u>
1	1.94	1.96	1.99	1.66	1.52	1.49
2	1.95	1.96	1.97	1.55	1.51	1.49
3	1.94	1.95	1.95	1.59	1.52	1.50
4	1.94	1.96	1.98	1.58	1.52	1.49
5	1.94	1.96	1.98	1.58	1.51	1.48
6	1.94	1.96	1.98	1.67	1.52	1.49
7	1.95	1.97	1.99	1.70	1.52	1.50
8	1.94	1.96	1.97	1.64	1.52	1.50
9	1.95	1.96	1.98	1.63	1.52	1.50
10	1.94	1.96	1.97	1.58	1.52	1.49
11	1.95	1.96	1.98	1.60	1.52	1.49
12	1.95	1.95	1.96	1.54	1.52	1.50
13	1.95	1.97	1.99	1.69	1.51	1.50
14	1.95	1.96	1.95	1.54	1.52	1.50
15	1.95	1.95	1.93	1.54	1.52	1.50
16	1.95	1.94	1.93	1.54	1.52	1.50
17	1.97	2.11	2.06	1.56	1.51	1.49
18	1.95	1.97	1.98	1.66	1.52	1.50

TABLE 13

## TEAR-DOWN DATA FOR BATTERY #8 - FAILED 364 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Circuit Condition of Cell Case	Leaked	Condition of Separators	Positive Plates	Negative Plates		Ag Penetration in Mg/in <sup>2</sup>							
						Creeping	Treeing Loss	Mat'l	1st Dynel	2nd Cello.	3rd Cello.	4th Cello.	5th Cello.	6th Cello.	7th Cello.
1*	1.84			Good	Formed	none	none	10%	6.5	64.7	3.0	.5	.4	.3	.1
2*	1.73			"	Partially formed	"	"	"	13.5	64.3	3.5	.6	.4	.3	.2
3	1.82			"	Formed	"	"	"	5.9	72.7	2.0	.2	.1	trace	-
4*	1.62			"	Partially formed	"	"	"	14.2	90.0	2.7	.3	.1	trace	-
5*	1.74			"	"	"	"	"	8.7	82.0	3.0	.2	.1	-	-
6*	1.68			"	"	"	"	"	8.0	84.7	3.5	.3	.2	.1	-
7*	1.62			"	"	"	"	"	6.2	96.8	3.8	.2	.2	.1	-
8	1.64			"	"	"	slightly at top	"	6.1	88.0	4.5	.3	.2	.1	-
9	1.67			"	"	"	"	"	11.8	81.0	2.0	.3	.3	.2	-
10*	1.68			"	"	"	"	"	7.7	86.5	1.7	.2	-	-	-
11*	1.70			"	"	"	none	"	7.1	78.2	4.0	.3	.2	-	-
12	1.73			"	"	"	"	"	5.0	85.7	3.8	.3	.2	-	-
13*	1.59			"	"	"	"	"	14.6	87.2	2.2	.2	-	-	-
14	1.74			"	"	"	"	"	4.2	70.2	3.7	.4	.3	-	-
15	1.80			"	"	"	"	"	6.7	79.7	5.6	.5	.3	.2	-
16	1.82			"	Formed	"	"	"	8.7	89.4	3.2	.5	.4	.3	.2
17	1.83			"	"	"	"	"	7.5	85.9	2.9	.4	.3	.2	.2
18	1.82			"	"	"	"	"	6.9	75.3	2.0	.4	.2	-	-

\* Cells that failed.

TABLE 14

## TEAR-DOWN DATA FOR BATTERY #9 - FAILED 421 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of separator along	Positive Plate	Creeping	Negative Plates	Mat'l Treeing Loss	1st layer Dynel	2nd FSC	3rd FSC	Ag Penetration in Mg/in <sup>2</sup>
1*	1.86	Sealed	Good	Formed	Very slight	Tops	35%	2.0	32.4	1.1	.2
2*	1.86	"	"	"	"	"	40%	1.8	24.1	.4	.1
3	1.86	"	"	"	"	"	35%	1.3	28.5	.7	-
4*	1.81	"	"	"	"	"	"	1.4	27.9	.8	.2
5*	1.86	"	"	"	"	"	40%	1.4	23.0	2.0	-
6*	1.83	"	"	"	"	"	35%	1.6	30.0	2.3	.1
7	1.86	"	Holes in 2 layers	"	"	"	35%	1.4	34.7	1.3	.1
8	1.82	"	Good	"	"	"	40%	2.1	33.5	1.1	.2
9	1.86	"	"	"	"	"	30%	1.5	35.5	1.3	.1
10	1.85	"	"	"	"	"	30%	1.9	37.8	2.1	.2
11*	1.86	"	"	"	"	"	35%	2.0	31.6	.7	trace
12*	1.84	"	"	"	"	"	"	1.9	30.0	.2	trace
13*	1.86	"	"	"	"	"	"	1.5	34.3	.9	.1
14*	1.82	"	"	"	"	"	"	1.5	31.9	1.9	.2
15	1.86	"	"	"	"	"	30%	3.3	34.4	.6	.1
16	1.86	"	"	"	"	"	"	1.3	32.9	1.2	.1
17	1.86	"	"	"	"	"	25%	1.1	39.2	1.5	.1
18	1.86	"	"	"	"	"	30%	1.1	29.1	.1	trace

\* Cells that failed.

TABLE 15

## TEAR-DOWN DATA FOR BATTERY #10 - FAILED 500 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Voltage after Charge	Circuit Condition of Cell Case	Condition of separators	Positive Plates	Negative Plates		Mat'l Loss	Ag Penetration in Mg/in <sup>2</sup>			
					Creeping	Treeing		1st layer Dynel	2nd FSC	3rd FSC	4th FSC
1	1.83	Leaked	Good	Formed	none	Top	30%	2.0	32.2	1.0	trace
2 *	1.86	"	"	"	"	"	40%	1.7	37.4	1.4	.3
3	1.85	Sealed	"	"	"	"	"	1.6	39.5	1.0	.1
4	1.85	"	"	"	slight creep	"	"	1.5	36.5	1.8	.3
5	1.85	"	"	"	"	"	"	1.5	31.6	1.7	.2
6	1.86	"	"	"	"	"	"	1.4	32.8	.8	.2
7	1.86	"	"	"	"	"	"	1.5	34.2	.8	.2
8	1.86	"	"	"	"	"	"	1.5	32.2	.4	trace
9 *	1.86	"	"	"	none	"	"	1.2	36.3	2.7	.1
10 *	1.86	"	"	"	slight	"	25%	1.3	41.0	2.5	trace
11 *	1.86	"	"	"	"	"	40%	1.7	40.1	1.0	-
12	1.86	"	"	"	none	"	35%	1.6	40.2	1.9	.2
13 *	1.60	"	"	Partially formed	slight	"	30%	1.8	41.0	3.0	.3
14 *	1.86	"	"	Formed	none	"	35%	3.7	34.3	2.8	.2
15 *	1.86	"	"	"	"	"	30%	1.4	39.4	.5	-
16 *	1.86	"	"	"	"	"	30%	1.2	36.2	2.8	.1
17 *	1.85	"	"	"	"	"	35%	1.7	39.0	2.7	.2
18	1.86	"	"	"	"	"	35%	1.3	33.5	1.2	.1

\* Cells that failed.

TABLE 16

## TEAR-DOWN DATA FOR BATTERY #11 - FAILED 420 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of Separators	Positive Plates	Negative Plates	Mat'l Creeping	Ag Penetration in Mg/in <sup>2</sup>			
							Treeing	Loss	1st Dynel	2nd FSC
1	1.85	Leaked	Good	Formed	around 2 Bottom, layers sides & top	25%	3.5	79.9	.5	-
2	1.84	"	"	"	"	30%	8.1	79.8	.5	-
3	1.86	"	"	"	"	25%	2.4	72.6	.3	trace
4	1.84	"	"	"	"	30%	4.5	73.0	.5	-
5*	1.82	"	"	"	"	35%	5.4	82.2	.4	trace
6*	1.57	"	"	Partially formed	"	30%	6.6	83.3	.2	-
7*	1.86	"	"	Formed	"	35%	6.4	80.5	.2	-
8*	1.86	"	"	"	"	35%	4.0	80.5	.2	-
9	1.86	"	"	"	"	35%	4.8	80.7	.3	-
10	1.86	"	"	"	"	"	7.4	86.4	.2	-
11*	1.86	"	"	"	"	"	6.8	85.0	.5	-
12	1.85	"	"	"	"	"	4.5	52.2	.2	-
13	1.86	"	"	"	"	40%	3.0	77.0	.2	-
14*	1.86	"	"	"	"	35%	2.0	80.2	.2	-
15*	1.86	"	"	"	"	35%	3.5	72.7	.5	-
16	1.86	"	"	"	"	25%	4.5	86.8	.2	-
17*	1.86	"	"	"	"	40%	5.3	74.9	.2	-
18*	1.86	"	"	"	"	30%	3.2	69.3	.2	-

\* Cells that failed.

TABLE 17

## TEAR-DOWN DATA FOR BATTERY #12 - FAILED 420 CYCLES

Note: The condition of plates and separators and silver deposition indicate an average per cell

Cell No.	Open Circuit Voltage after Charge	Condition of Cell Case	Condition of Separators	Condition of Plates	Positive Plates	Negative Plates	Mat'l	Ag Penetration in Mg/in <sup>2</sup>				
								Discharged	Around 2 layers	Tops	Loss	1st Dynel
1*	1.43	Leaked	Good		Discharged	Around 2 layers	Tops	40%	2.9	66.8	.5	.2
2	1.86	"	"	Formed		"	"	40%	4.7	66.0	.6	.2
3*	1.86	"	"	"	"	"	"	50%	3.0	61.3	.3	trace
4*	1.83	"	"	"	"	"	"	"	3.0	50.8	.3	trace
5*	1.85	"	"	"	"	"	"	"	7.8	67.9	.2	trace
6	1.86	"	"	"	"	"	"	"	4.6	73.7	.6	"
7*	1.53	"	"	Partially formed		"	60%	9.2	55.5	.4	"	"
8	1.86	"	"	Formed		"	50%	4.5	76.7	.3	"	"
9	1.86	"	"	"	"	"	50%	5.1	59.7	.2	"	"
10*	1.86	"	"	"	"	"	50%	4.6	77.4	.2	"	"
11	1.86	"	"	"	"	"	50%	8.4	61.5	.5	"	"
12	1.86	"	"	"	"	"	50%	5.7	58.5	.5	"	"
13*	1.62	Sealed	"	Partially formed		"	50%	5.5	74.0	1.4	.2	.2
14	1.86	Leaked	"	Formed		"	50%	3.0	78.5	.3	trace	"
15	1.84	"	"	"	"	"	45%	2.3	67.2	.2	"	"
16*	1.86	"	"	"	"	"	45%	3.1	70.5	.8	.2	.2
17*	1.71	"	"	Partially formed		"	50%	7.4	63.7	.3	-	-
18	1.86	"	"	Formed		"	50%	3.5	64.7	.5	.2	.2

\* Cells that failed.

TABLE 18  
 BATTERY NO. 11  
 87th Cycle

<u>Cell #</u>	<u>Charge</u>			<u>Discharge</u>		
	<u>20 min.</u>	<u>60 min.</u>	<u>85 min.</u>	<u>5 min.</u>	<u>20 min.</u>	<u>35 min.</u>
1	1.93	1.93	1.95	1.80	1.53	1.52
2	1.92	1.93	1.95	1.80	1.53	1.52
3	1.92	1.93	1.94	1.79	1.54	1.52
4	1.92	1.95	1.96	1.69	1.54	1.52
5	1.92	1.94	1.95	1.80	1.54	1.52
6	1.92	1.94	1.96	1.80	1.54	1.52
7	1.92	1.94	1.97	1.80	1.54	1.52
8	1.92	1.94	1.95	1.80	1.54	1.52
9	1.92	1.94	1.95	1.78	1.54	1.52
10	1.92	1.94	1.95	1.80	1.54	1.52
11	1.92	1.94	1.94	1.79	1.54	1.52
12	1.92	1.95	1.96	1.63	1.54	1.52
13	1.92	1.94	1.95	1.78	1.53	1.52
14	1.92	1.95	1.95	1.60	1.54	1.52
15	1.92	1.95	1.96	1.67	1.54	1.52
16	1.92	1.94	1.95	1.78	1.54	1.52
17	1.92	1.94	1.94	1.78	1.54	1.52
18	1.92	1.95	1.94	1.76	1.54	1.52

TABLE 19  
BATTERY NO. 11

336 Cycles

Cell #	Charge			Discharge		
	20 min.	60 min.	80 min.	5 min.	20 min.	35 min.
1	1.94	1.92	1.91	1.61	1.52	1.47
2	1.95	1.97	1.97	1.72	1.52	1.48
3	1.95	1.98	2.01	1.75	1.52	1.50
4	1.95	2.00	2.05	1.76	1.52	1.49
5	1.94	1.96	1.95	1.74	1.51	1.48
6	1.95	1.98	1.98	1.74	1.52	1.49
7	1.94	1.98	1.99	1.76	1.52	1.50
8	1.94	1.95	1.96	1.76	1.52	1.50
9	1.94	2.09	2.08	1.76	1.52	1.49
10	1.94	1.96	1.96	1.73	1.52	1.49
11	1.95	1.95	1.94	1.67	1.52	1.49
12	1.94	1.98	2.01	1.76	1.52	1.50
13	1.95	1.98	1.99	1.76	1.52	1.50
14	1.95	1.98	1.98	1.74	1.52	1.50
15	1.94	1.96	1.96	1.73	1.52	1.50
16	1.94	1.99	2.02	1.76	1.52	1.50
17	1.95	1.97	1.97	1.72	1.52	1.50
18	1.94	1.97	1.97	1.73	1.52	1.50

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Rpt No. ASD-TDR-62-668, DEVELOPMENT OF  
SEALED SILVER OXIDE-ZINC SECONDARY BATTERIES.  
Final report, Oct 62, 142p incl illus,  
tables, 263 refs.

Unclassified Report

Research and development program was con-  
ducted to provide an hermetically sealed  
silver oxide-zinc battery for use in satellite  
applications. Problem areas considered  
were: silver migration in cell, battery  
voltage regulation, zinc particle size and  
displacement during cycling, gas evolution,

( over )

and terminal sealing. Sealed cells were  
designed, constructed, and tested elec-  
trically and environmentally. Eighty-nine  
cells were cycled to failure. On basis  
of cell testing, batteries were designed,  
constructed and life-cycle-tested. Twelve  
batteries were cycled to failure; one  
additional battery was tested environ-  
mentally.

1. Silver-zinc batteries  
2. Satellite batteries  
3. Batteries  
I. AFSC Project 8173  
Task 817304  
II. Contract AF33(600)-  
41608

III. Delco-Remy Division  
of General Motors  
Corporation,  
Anderson, Indiana

IV. J. J. Lander  
J. A. Keralla  
V. Aval fr OTS  
VI. Not eval fr OTS

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